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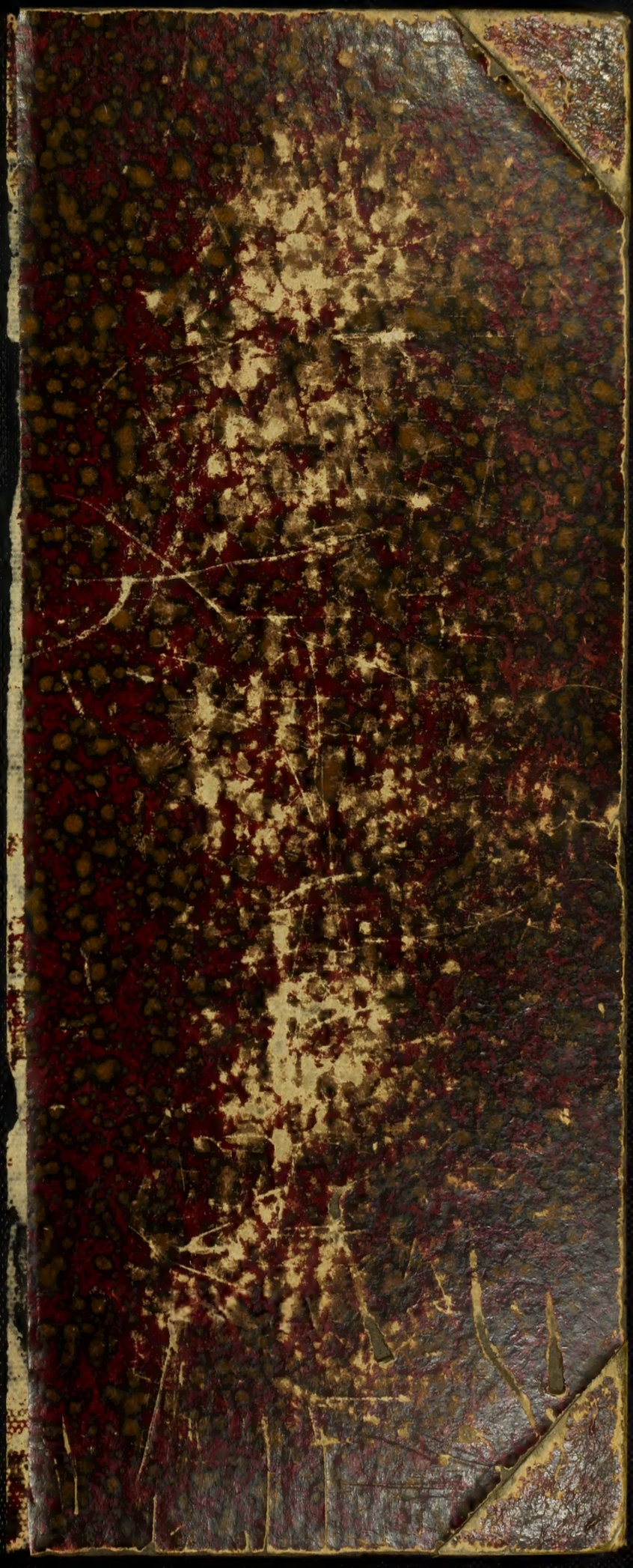
An Investigation of Hooped Concrete Columns

Theoretical and Applied Mechanics

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AN INVESTIGATION OF HOOPED CONCRETE COLUMNS

BY

HOWARD RICE THOMAS

C. E. University of Texas

1912

THESIS

Submitted in Partial Fulfillment of the

Requirements for the

Degree of

MASTER OF SCIENCE

IN THEORETICAL AND APPLIED MECHANICS

IN

THE GRADUATE SCHOOL

OF THE

UNIVERSITY OF ILLINOIS

1914

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May 30, 1914. 190

I HEREBY RECOMMEND THAT THE THESIS PREPARED UNDER MY SUPERVISION BY

HOWARD RICE THOMAS

ENTITLED AN INVESTICATION OF HOOPED CONCRETE COLUMNS

BE ACCEPTED AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE

DEGREE OF MASTER OF SCIENCE IN THEORETICAL AND APPLIED MECHANICS.

A N Talbot
In Charge of Major Work

A N Talbot
Head of Department

Recommendation concurred in:

Committee
on
Final Examination

278419

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1. Preliminary.- Since the time Considere made his first experiments with spiral-hooped columns, many such tests have been made. But in practically all these cases the longitudinal deformations were measured over long gage lengths and the lateral deformations by measuring the change in diameter of the column. In none of these were measurements made on gage lines short enough or at a sufficient number of points on a column to enable one to see the effect of local weaknesses in the column. Nor have measurements been made to determine the relation between the lateral and longitudinal deformations at loads approaching the ultimate. It is only within the last two or three years that the use of the"strain gage" has been developed to a sufficient extent to render it feasible for making such measurements of lateral and longitudinal deformations at various points in a column. At present it is entirely practicable to take measurements on as high as 200 gage lines on a specimen.

During the early part of the year 1913, twelve plain concrete columns and three spiral-hooped columns were made at the University of Illinois Experiment Station. These were tested in the summer of 1913, and strain gage readings were taken on many gage lines. These columns were made with the idea of studying the effect of length, this being the only variable entering the two series. From the results of these tests it was decided that a series of tests of this kind on a larger scale

was desirable in order to study the effect of other variables on the relative deformations. It was with this idea in mind that the tests described in this thesis were planned.

2. Scope.- This thesis contains the results of the tests of three plain concrete columns and twenty six spiral-hooped concrete columns. The tests were intended to give results showing the effect of variation in length on the relative deformation (8 columns), the effect of variation in per cent spiral (13 columns) and the effect of variations in mixture (9 columns). There was also one set of three 20-ft. columns which contained five 1-in. round longitudinal bars. These columns were expected to show the effect of longitudinal reinforcement on the strength of long columns.

3. Acknowledgment.- These tests were made in the University of Illinois Engineering Experiment Station, under the direction of Prof. A. N. Talbot. The writer is indebted to Professor Talbot for many valuable suggestions both in making the tests and in interpreting results. The writer also desires to express his appreciation of the valuable criticism of the thesis by Mr. W. A. Slater, First Assistant in the Engineering Experiment Station, who read the thesis in manuscript form. Mr. G. A. Maney and Mr. Julian Montgomery, Research Fellows in the Experiment Station, were of invaluable assistance in making the tests for this thesis.

4. Theory, Formulas, etc.- While many formulas for the strength of spiral-hooped columns have been proposed, practically all of them are based upon the ultimate strength of the

column and only a few upon loads below the "yield point".

It is a comparatively simple matter to derive a formula based on the elastic properties of materials, which, with the proper choice of constants, will give the stress in the spiral with some degree of accuracy up to the "yield point" of the column, or up to the load corresponding roughly to the strength of the concrete alone.

The following derivation is readily followed:

Let:

μ = Poisson's ratio.

p = steel ratio (ratio of vol. of spiral to enclosed vol. of the col.)

r = radius of helix.

f_c = long. compressive unit stress in the column.

f_s = unit stress in spiral steel.

P = normal lateral compressive unit stress on column.

e = lateral unit deformation.

t = thickness of equivalent thin pipe giving the same % steel as p.

e_x = deformation along x - axis.

F_x = stress in direction x.

F_y = stress in direction y.

F_z = stress in direction z.

Assuming that the action of the spiral is the same as if it were spread over the column as a thin pipe, we have:

$$t = \frac{pr}{2}$$

and $2Pr = 2tfs.$

$$P = \frac{tfs}{r}$$

$$P = \frac{pfs}{2}$$

For a homogenous material subjected to stresses in more than one direction, we have the well known formula:

$$e_x E = F_x - \mu(F_y + F_z)$$

$$eE = P - \mu(P + f_c)$$

$$(P = F_x = F_y)$$

$$e = \frac{1}{E}(P - \mu(P + f_c))$$

But the actual lateral unit deformation $= \frac{-f_s}{E_s}$.

$$-\frac{f_s}{E_s} = \frac{1}{E_c}\left[P - \mu(P + f_c)\right]$$

$$-f_s = n\left[\frac{pf_s}{2} - \mu\left(\frac{pf_s}{2} + f_c\right)\right]$$

$$= n\left[\frac{pf_s}{2}(1 - \mu) - \mu f_c\right]$$

$$-f_s\left[1 + \frac{pn}{2}(1 - \mu)\right] = -n\mu f_c$$

$$-f_s = \frac{-n\mu f_c}{1 + \frac{pn}{2}(1 - \mu)}$$

$$\frac{f_s}{f_c} = \frac{+\mu}{\frac{1}{n} + \frac{p}{2}(1 - \mu)}$$

By a reasonable choice of values of μ and n, it will be found that this formula gives fairly close results up to the "yield point" of the column.

After the yield point is passed, μ and n become such rapidly changing variables that it would be almost impossible to apply the formula, even if it were a rational one to use for such conditions. But in deriving this formula it was assumed that the column to which it is to be applied is of an elastic homogenous material and subject to the laws governing

such bodies. While this is approximately true for concrete at low stresses, it is not even an approximation to the truth at high deformations. After the yield point of the column has been passed, it is probable that the material acts somewhat like a granular mass with a thin steel shell around it. But even in this case, the granular material is probably one having an angle of repose (or coefficient of friction) varying with the amount of load to which it has been subjected. It is also probable that there is considerable and variable cohesion among the particles, and so it would be almost impossible to derive a rational formula that would take account of all of these variable factors and still be usable. Of course such a formula might be derived for the ultimate strength of a concrete column, but even in this case the cohesion and angle of repose would be a variable for each different concrete.

Both the results of tests and the results given by the above formula indicate that the stress in the spiral at the yield point of the column is very small, being at most a few thousand lbs. per sq. in. Beyond this point, as explained above, the properties change rapidly and the formula no longer applies.

II. MATERIALS, SPECIMENS, APPARATUS, ETC.

1. Materials and Properties.- The materials used in making the concrete for these tests were the same as have been used for a number of years in making the test specimens for the Engineering Experiment Station.

Cement.- Universal Portland cement was used, the tensile strength of which is given in table I.

TABLE I

Tension Tests, Universal Portland Cement

Sample 1.

Initial Set. - 4h. - 55m.
Final Set - 8h. - 0 m.

	7 day		28 day	
No.	Neat	1:3	Neat	1:3
1	575	190	730	335
2	590	185	750	295
3	620	185	755	295
4	600	185	735	280
5	635			
Ave.	604	186	742	301

Sample 2.

Initial Set. - 1h. - 5 m.
Final Set - 5h. - 25m.

	7 day		28 day	
No.	Neat	1:3	Neat	1:3
1	600	180	705	189
2	595	190	705	295
3	605	200	675	295
4	590	205	650	275
5	610		710	
Ave.	600	194	689	288

Sand.- The sand was a well graded one from the pits near Attica, Indiana, being screened thru a 1/4-in. mesh screen.

Stone.- A hard limestone from near Kankakee, ordered screened to passa 1-in. screen, was used. In the columns made on and after Nov. 20th, 1913, (which includes practically all the columns), the stone was of a new shipment received on that date.

Steel.- The steel used as longitudinal reinforcing was taken from the stock on hand. It had a yield point of 33,300 lb. per sq. in. and an ultimate strength of 50,500 lb. per sq. in.

Six 24-in. test pieces of each size of the spiral wire were furnished by the manufacturers of the spirals. The 1/2-in. rods were tested in the 50,000-lb. Riehle machine and the 5/16-in. and 3/16-in. sizes were tested in the 10,000-lb. Olsen wire-testing machine. Elongation in 8-in., reduction in area, and ultimate loads were determined for each specimen; measurements of elongation over a 2-in. gage length were also made for each test by means of an extensometer designed by Professor H. F. Moore of the University of Illinois. The results of these readings gave smooth curves, which are shown on pages 40–43. It should be noticed there is no break in these curves such as would indicate a definite yield point, nor was any "drop of beam" noticed in testing. From appearances these test specimens were probably straightened out after having been bent into spirals. This straightening would probably in some measure account for the lack of a definite yield point.

The tests of the 3/16-in. wires indicate that this size of reinforcing does not fulfill the requirements of the Specifications for reinforcing rods made from rails (or for high carbon steel rods), as given in the Year Book of the American Society for Testing Materials for 1913. These requirements are tensile strength = 80,000 lb. per sq. in. (actually 78,500); yield point = 50,000 lb. per sq. in. (about 65,000 lb. per sq. in., but not definite), % elongation in 8 in. = $\frac{1,200,000}{\text{tensile str.}} - 4 =$ $\frac{1,200,000}{78,500} - 4 = 11.3\%$ Actual elongation = 2.11%
The steel stood the bending around a bar of 3 times its own diameter without sign of failure.

The necking of these bars at the point of rupture occurred over a very short length, but there was a large reduction of area (59.1%). This necking was very much like that found in the testing of cold drawn wires.

2. Specimens.- The columns were all approximately 12-in. in diameter center-to-center of the spirals. Three lengths of columns were tested, these being 5 ft, 10 ft. and 19 ft.-8in.

The spiral reinforcing for these columns was furnished thru the courtesy of the Concrete-Steel Products Co. of Chicago. The spiral consisted of a circular helix held at the proper pitch by means of two spacing bars. In the five and ten-ft. columns, this spiral was in one piece but in the 20-ft. ones it was made of two 10-ft. sections having the ends anchored at the center of the length of the column by bending the end of the spiral toward the center of the column. The spacing bars in all of these extended the full length of the column. The spacing bars were made of 3/16-in. x 1 1/2-in. flats having slots cut at the proper distances apart to receive the spiral. The wires were held by bending down the tongues left in cutting the slots.

It was desired to use the same pitch of spiral of 1-in. in all the columns, but it was found that the manufacturers were unable to make a spiral having a pitch of 1-in. with the size of wire necessary to give four to five per cent of spiral, so for the largest per cent of spiral a pitch of 1 1/2-in. was used. From previous tests it was thought that the variations in pitch within these small limits would have practically no

effect upon the strength or behavior of the columns.

In shipment, the long spirals were bent double in placing in the car (the two spacing bars permitting this) and also some of the shorter lengths had bad kinks in them when they were received. When the spirals were straightened out in the laboratory, it was found that in places the spirals had become loose in the spacing bars and had untwisted, thus making variations in the diameter of the column. This untwisting had also caused the spacing bars to assume a curved shape, as shown in the photograph page 211. These difficulties made it almost impossible to make straight columns of uniform diameter. This trouble could have been obviated by using three spacing bars, as is often done.

Auxiliary Specimens.- Three 6-in. cubes and one cylinder 8-in. x 16-in. were made from each batch of concrete in order to determine the strength and modulus of elasticity of the concrete used. The auxiliary specimens for the 20-ft. columns were made from the two batches after they had been mixed. In all cases these specimens were made after the forms had been filled about half full, with the idea of securing results that were as near the average of the whole batch as possible.

Extensometer readings were taken on the cylinders and the ultimate loads determined for the cubes. The load - deformation curves for the cylinders are plotted on pages 44 to 47. The numbers are the same as those of the columns to which the cylinders belong. The ultimate strengths of the cylinders and cubes and the ages at which they were tested are given in table VI.

3. Forms.- The forms were made of 2 1/2-ft. sections of sheet iron clamped to the spirals by means of iron straps fastened with bolts. It was found that with these sectional forms it was almost impossible to secure straight columns, the two spacing bars on the spirals allowing the spiral to bend too readily. Heretofore no such difficulty had been found with spirals having three spacing bars. While there was not much trouble with the 5-ft. columns, even these were not always as straight as was desired. With the 10-ft. and especially with the 20-ft. columns, it was only by a great deal of labor that even approximately straight columns were secured. For the 20-ft. columns the forms were put together around the spirals while lying on the floor after they had been straightened out as much as possible. The forms were then rolled on to a ladder and lifted into place by means of a hoist. It was necessary to use several braces to hold them straight after raising them.

The forms for the other two sizes of column were also put together while they were lying down, but they were rigid enough not to have to use a support for raising them.

After four of the 20-ft. columns had been made with the sectional forms, it was found that none of them was perfectly straight and that one (8919) was too crooked to be worth taking, certain parts being about 1 in. out of alignment. It was decided that the tests of such crooked columns would have no value, and that it was not worth while to make any more unless straight ones could be secured.

Finally it was decided to use a piece of 13-in. pipe

the full length of the column as a form. This pipe was split into four sections, for ease in removing, and sufficient narrow wooden strips were used between the sections to allow for the variation in diameters of the different spirals. The sections were held together by bands placed close enough together to prevent the pressure of the wet concrete from causing the wooden strips to bulge out.

By the use of this form, the last five of the 20-ft. columns were made almost perfectly straight.

4. Fabrication.- The concrete in all these columns was mixed in a 1/3 yd. March-Capron mixer. The work was done under the direction of Mr. D. A. Abrams, by mem experienced in making concrete, who havemade the test specimens used in the laboratory for a number of years. The materials were measured in buckets, and then weighed as a check on the measurements. The materials were thoroughly mixed while dry, and then mixed for five minutes after the water was added. Enough water was used to give a medium wet mixture which would thoroughly cover the spirals. The amount of water used was measured in each case.

In some cases two five-ft. columns were made from one batch of concrete, but in no case were these two columns of the same series. In putting the concrete into the forms where two columns were made from the same batch, alternate bucketfuls were placed in each in order to secure both columns as nearly alike as possible.

This precaution of not making two columns of the same series from the same batch has been found necessary in order that any accidental variation in a given batch may not cause phenomena

that might otherwise be ascribed to the effect of the variable of that series. This precaution has too often been disregarded in making concrete test specimens.

In making the 20-ft. columns, two batches of concrete were necessary. The first batch was mixed and turned out on the floor, and then the second mixed and dumped on it. These two were then thoroughly stirred together to secure a homogenous concrete.

A planed cast iron bed plate was used for each column. In setting up the form, this bed plate was carefully leveled. The spiral in the form was placed on the plate and plumbed, braces being used to hold it in position. The concrete was handled by the bucketful, and was thoroughly stirred as each bucketful was added. The tamper, which was used for stirring, rather than tamping, consisted of an iron head about 3-in. in diameter with a sectional pipe handle. The concrete was too wet to be tamped, but it was thoroughly stirred in order to cause it to flow around and cover the spirals and also to remove as much entrained air as possible.

After filling the form, the concrete was given an hour or so in which to settle, the top was then smoothed off and a plate like that used on the bottom was placed on the top.

5. Storage.- The cylinders and cubes were left in the molds for 7 days and were then stored in damp sand until time for testing. A day or two before they were tested, they were taken to the laboratory and the ends set in plaster of paris in order to obtain a smooth bearing area. The forms were removed from

the columns at the end of 7 days. The columns were stored in the room in which they were made until time to get them ready for testing. This room was steam heated and was kept at a temperature of about 70 degrees. During the time the specimens were in this room, the columns and the sand in which the auxiliary specimens were kept were frequently sprinkled.

6. Handling of Specimens.- A few days before a column was to be tested it was hauled to the testing laboratory where it was gotten ready. In hauling these, the base and top plates were securely bolted together and the columns then laid down on blocks on the wagon. Fig. 15, page 211, shows a column in the cement laboratory bolted up ready for hauling. The 20-ft. columns were placed on an I-beam which was unloaded and handled in the laboratory by using rollers.

The five-ft. columns were readily "walked" into the testing machine by one man, but it was necessary to use a hoist on the 10-ft. ones. The 20-ft. columns were run part of the way into the testing machine while on the I-beam. A chain attached to the column about 5 ft. from its upper end and to the movable head of the testing machine made it possible to lift the column into position by running up the head of the machine. While raising the column, the lower end was rested on a board placed on two dollies.

7. Preparation.- Before being placed in the testing machine, the columns were prepared by locating and drilling the gage holes. It had been found that in taking readings on gage lines located on small round bars, the angle of the instrument

had considerable influence on the readings obtained. This was especially true when the gage hole was not drilled exactly radially in the bar. This difficulty was overcome in a large measure in these tests by grinding a small flat spot for each hole by means of an emery wheel attached to a flexible shaft run by a motor. This method was used in all the tests in this thesis and proved very satisfactory. All of the gage lines for measuring lateral deformation had a gage length of four inches.

The holes for the longitudinal gage lines were drilled in plugs set flush with the surface of the concrete at the proper distance apart. These plugs were made of 1/2-in. round bars cut to 1-in. lengths. The holes for these were drilled with 1/2-in. star drills, the top half of the hole being chipped to a larger size to allow room for enough plaster of paris to hold the plug steady. In setting, the holes were filled with plaster of paris and the plugs were then driven in to a solid bearing. No trouble was experienced with loose plugs, except in a few cases where these were cut from 7/16-in. rods. These were readily tightened by driving two or three short brads in the plaster by the side of the plugs. In general, the longitudinal gage lines were nine inches long where the pitch of the spiral was 1 1/2-in., and 10in. for the 1-in. pitch, but there were some exceptions.

Except the first two columns, all the getting ready and drilling the holes was done by one of the workmen in the laboratory, and to his careful and rapid work is due, to a large extent, the possibility of making the large number of tests in

a comparatively short time.

8. Testing.- The columns were placed in the testing machine and the upper end carefully centered between the screws. After taking off the rods the head of the machine was run down until the spherical bearing block rested on the upper plate. The block was then shifted so as to give as near an axial loading as possible. It is believed that the center of the block was set to within an eighth of an inch of the center of all columns tested.

Zero readings were taken with only the weight of the bearing block on the column. After the first increment of load (usually 250 lb. per sq. in.) had been applied, the bearing block was fixed by means of angle blocks and wedges to prevent rotation, - that is, - to make a fixed ended column. These blocks and wedges can be seen in position in the photograph page 204.

In all tests the load was applied with the speed of the head of 1/10-in. per minute.

III. EXPERIMENTAL DATA AND DISCUSSION.

1. Notation.- The notation used will be that found in most modern text books.

2. Explanation of Tables.- In table I are given the results of tensile tests of the cement and cement mortar at the ages of 7 days and 28 days. Table II gives the results of tests of the steel used in the spirals. Table III gives the weight of cement, sand, stone and water used in making the concrete for each column. It includes also the ratio (expressed as per cent) of the weight of water to the weight of dry materials.

Table IV gives the values of the average load per sq. in. and longitudinal unit deformation for columns 8901-8918 at various stresses in the spiral. These are given for the top, center and bottom of the column and the average values for the three columns of each group are tabulated. The values of $\frac{1}{\mu}$ given in the last column are calculated from the average longitudinal unit deformation and the unit deformation in the spiral. In figuring the average for the whole spiral the individual averages were weighted according to the number of values which were used in obtaining the average.

Table V gives the values of the moduli of elesticity for the various columns at top, center and bottom and also the average. The average values for the corresponding cylinders also are tabulated.

Table VI is a record of the various dimensions and properties for all of the columns. It gives the dates on which the columns were made and tested, the results of the auxiliary

tests and a few of the more important general results of the tests.

3. Explanation of Curves.- On pages 40 to 43 are given the stress deformation curves for the steel in the spirals. On pages 44 to 47 are given the load-deformation curves for the cylinder tests. The numbers are the same as the columns to which they correspond. The load stress or load deformation curves for all gage lines of all the columns are given on pages 48 to152 . The object in including all of these was to put all the observed data in the thesis in the form of curves rather than in tables. On pages 152to 178are given the "distribution" curves for certain of the tests. These curves are plotted so that they show the variation in stress or deformation along the length or on a circumference of the columns for various loads. On pages 180to 199are given the average curves for all of the shorter columns and for some of the long columns. In making the averages for these columns, where circumferential bands were located on the columns the average value was found for all the lateral gage lines in the band. The average of the longitudinal gage lines that crossed the band was then found and tabulated. These averages were figured at each load, and then the average curves plotted from them. When readings were taken on the four sides of the column and no circumferential bands were taken, then each average was an average of four gage lines. An exception to this is found in some of the longitudinal gage lines for the long columns in cases where eight gage lines were located around the column. In some of the 5-ft. columns readings of lateral

deformation were taken on concrete plugs located between two readings on the spirals. For these, the curves marked "steel" are averages of eight readings, and those marked "concrete" are averages of four.

On pages 30A to 30C are given some average result curves obtained by plotting in various ways the results given in table IV. These curves are further discussed later. The method of plotting in each case is obvious.

4. Explanation of Drawings and Photographs.- On pages 200 to 211 are given photographs which show some of the most characteristic features of the tests. Attention is called to the peculiar features of the photograph on the sheet on which it is shown. On pages 221 to 249 are drawings which show the location of the gage lines of all the columns tested. These gage lines are located on the surface of the column which is shown as if unrolled, i. e., developed.

5. Phenomena of Tests.- In the following section are given some of the notes on the behavior of each column during the test. Where the word "deflection" is used, it should be understood as meaning the deflection of the point in question measured from a line tangent to the top and bottom of the column. The deflection before testing was measured in the same way and indicates the straightness of the column.

8901

Beyond the load 200,000 lb., the column took load very slowly. At 214,000 lb. load considerable scaling at gage line 24 on east side, but practically no scaling at the bottom. Spi-

rals broke at the following gage lines at the loads given: 6 at 239,000 lb., 26 at 240,000 lb., 24I, 24, 25 and 250,000 lb. max. load 250,000 lb.

It should be noted that the spiral in this column was very irregularly spaced, as shown in the drawing page 221 and in the photographs, pages 200-202. Also, by mistake the series of gage lines were not located 90° apart. The actual location is shown on page 221.

8902.

Scaling at 240,000 lb., principally near the bottom of column.

Spiral broke thru gage line 28 at 310,000 lb., 11, 12, 29I and 30 at 316,000 lb. maximum load 316,000 lb.

Spirals slightly more regular than 8901. See drawing page 221.

8903.

First scaling at 227,000 lb. At 305,000 lb. spiral broke at gage line 18 E. 3 C and 18 A broke at 318,800 lb. (Ultimate)

8904.

Slight amount of scaling noticed at the load of 209,000 lb. At the load 464,500 lb., deflection at the center of the west side was 1 7/16-in, All gage holes in the spiral stretched to oblong shape at the ultimate load.

8905.

Scaling at 245,000 lb. At 400,000 lb. bending at center toward south. Columns probably considerably stiffened against bending by spacing bars, which were in the plane of

bending. Ultimate load 502,000 lb. Total shortening 3 in.

8906

Scaling at 215,000 lb. Failure by bending at center toward S. E. Ult. load 491,000 lb. Total shortening 2 5/8 in.

8907

Each load was held constant (see page 26ff) forfive minutes before starting to read. Scaling at 180,000 lb. Column had not reached its ultimate strength at the load 603,000 lb., but there was a very slight bending perceptible. Total shortening at maximum load was 2 1/2 in.

8908

Scaling at 203, 500 lb., more at bottom than at top. At 600,000 lb. column had begun to bend toward east slightly below center. Total shortening 1 7/8 in.

8909

Scaling at 240,000 lb. load. Capacity of machine reached without failure of column. Total shortening 1 1/2 in, Before testing there was a deflection of 3/8 in. at the center on the west side, but this did not seem to affect the test.

8910

Before testing there was a deflection of 7/16-in. at the center on the east side, and a deflection of 1/4-in at the center on the north side. The other two sides were straight. At 316,000-lb. scaling at center of north side. Column failed by bending at center toward the west. Deflection at the center on the east side was 15/16-in. at the ultimate load of 500,000-lb.

8911

Scaling at 412,000-lb. Ultimate load 590,000-lb. Bending very slight at ultimate load. Total shortening 1 1/8-in.

8912

Before testing there was a deflection at the center of the south side of 1/8-in., and at the center of the west side of 1/4-in. Scaling at 418,000. At Ult.load of 584,000, deflection of 1/2-in. at center of west side. Total shortening 1-in.

8913

Scaling at 158,000-lb. At 311,000-lb. scaling more at bottom than at top. Ultimate load 446,000-lb. Deflection on north east side at ultimate load was 1.6-in. Bottom badly crushed on south west side.

8914

Scaling at 135,600-lb. At 300,000-lb. bending toward the north at the center was visible. Failure by bending. Ultimate load 414,000-lb. Total shortening was 3 1/8-in.

8915

Scaling at 120,000-lb. Pitch of spiral not uniform near bottom. At the bottom of column, spiral not well covered. Bending toward the south west started at the load 260,000-lb. Ultimate load 420,000-lb.

8916

Scaling at 141,000-lb. Bent toward west at center. Ultimate load 266,000-lb. At ultimate load, deflection of 3 1/2-in. on east side between gage lines 65 and 66.

8917

Before testing there were deflections of 5/8-in. at the

center of the west side, and of 5/16-in. at the center of the south side. North side straight. At the bottom of the column on east side offset of 1-in. from a line tangent to upper half.

At 192,500-lb. scaling at center west side. At 220,000-lb. there was a deflection at the center of the west side of 1 1/4-in. Before reaching the ultimate load, top and bottom of column on east side crushed and column bent as if round-ended.

8918

Scaling at 283,000-lb. Failed by bending toward south west Ultimate load 350,000-lb. Total shortening of 1 1/2-in.

8920

Scaling at about 240,000-lb. Failed by bending toward east at gage line 103. Upper end not perfectly fixed. Ultimate load 276,000-lb. At ultimate load deflection on west side 1-ft. below gage line 103 was 1 1/2-in.

8921

At 79,200-lb. slight scaling on east side at top, but nowhere else. This was possibly due to weak concrete here, and to driving in wedges too tight on that side. At 226,000-lb. scaling below top. Failed by bending toward south west at ultimate load of 252,000-lb. Deflection at ultimate load at gage line 146 was 1/5-in. Column bent as if fixed at both ends.

8922

Scaling occurred at 180,000-lb. Slight bending also at this load. Column bent toward south with point of maximum deflection at about 1/3 point from the top at the ultimate load. (See photograph page 206 Readings taken on this column

to find how the dropping off of load affected longitudinal deformation and lateral stress. At the ultimate load of 192,000-lb. deflection 12 ft. from bottom on north side was 4.7-in.

8923

The following deflection were measured before testing:

N. side, deflection opposite gage line 64 of 1/2 in.

E. " " " " " 64 of 1/2 in.

S. " " " " " 69 of 3/8 in.

W. side practically straight.

At 150,000 lb. column began to bend toward south east with point of maximum deflection at about 1/3 point from the top. Deflection 12 ft. from bottom at ultimate load of 180,000 lb. was 4.7 in.

8924

Scaling began near top at 183,000 lb. Failed by bending toward south west at about gage line 63. Upper end not perfectly fixed. Ultimate load 222,000 lb. Spiral near bottom not well covered.

8925

At 258,000 lb. bending toward west above center. Crushing at top on west side but not much at the bottom. At 264,000 longitudinal steel was scaling. At ultimate load of 264,000 lb., column had deflection of 1/6 in. at a point 12 ft. from bottom on east side, but there was not much scaling.

8926

At 327,000 scaling at center of east side and top and bottom of west side. Very slight deflection at center toward

west. At the ultimate load of 346,000-lb., the deflection at the center on the east side was 1 1/2 in. At the ultimate load scaling on the east side occurred principally above the center, at gage lines 45 and 65.

8927

At 220,000 lb., scaling occurred at the top at the reduced area where holes were cut in to the longitudinal steel. This scaling may also have been due to the fact that the longitudinal bars did not have a bearing on the top plate. At 280,000 lb., scaling began slightly above the center. Failure by bending toward the east between gage lines 5 and 6. At the ultimate load of 314,000 lb., there was a deflection of 1.6-in. 10-in. below gage line 6. All longitudinal bars had a bearing on the bottom plate, and were about 3/4 in. from the top plate.

8928

Failure by crushing below the center at the ultimate load of 235,000 lb.

8929

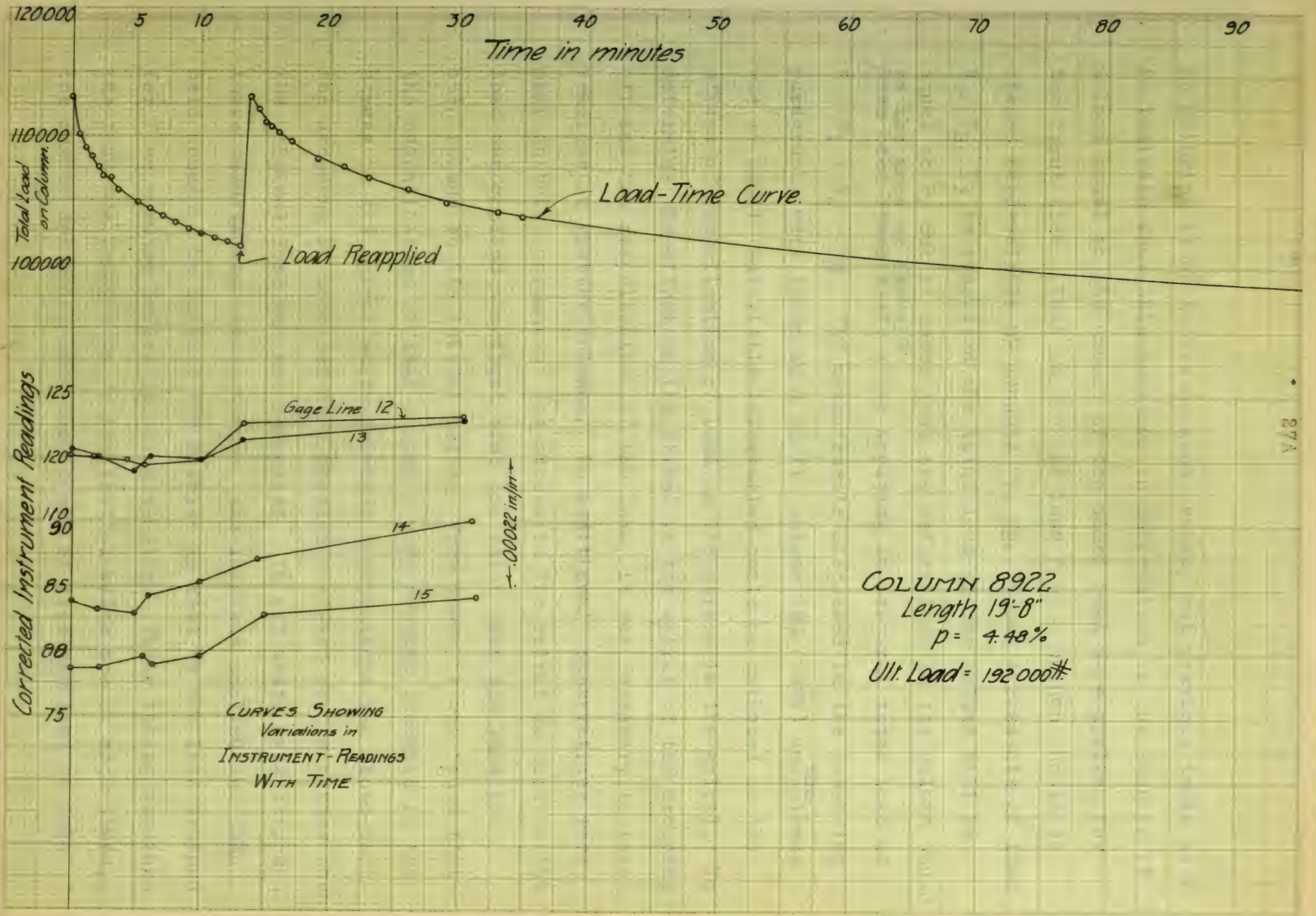
Failure by crushing on an inclined plane below the center. Fine vertical cracks near gage line 9 noticed at the load 192,000 lb. Ultimate load 203,000 lb.

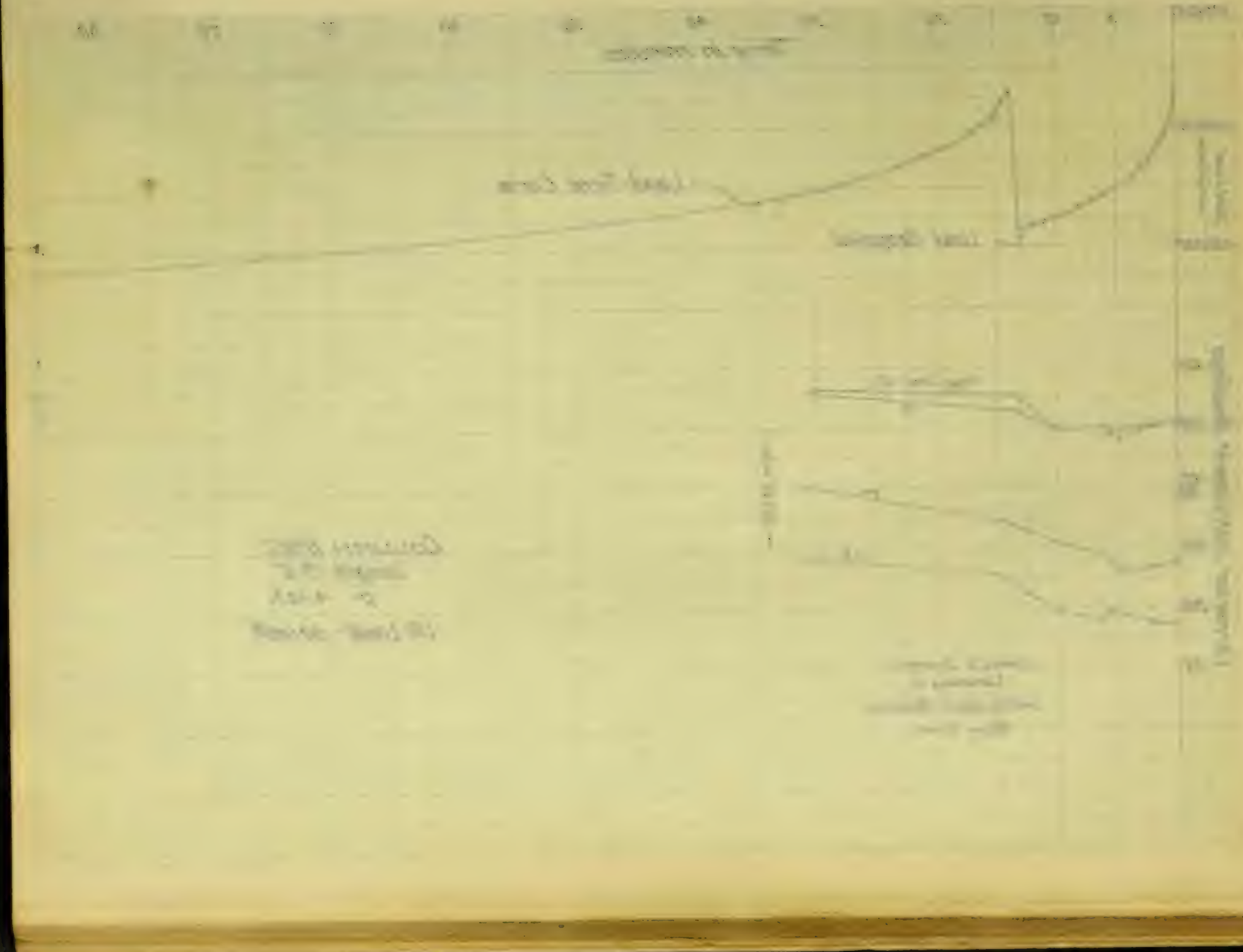
8930

Failure by crushing on inclined plane. Ultimate load 222,000 lb. Fine cracks below center noticed at 199,600 lb.

6. Analysis of Data. With the exception of the first increment of load, it was found that in the time required to take a set of readings the load dropped off considerably. The amount of this dropping

off increased with an increase in load, being rather small for loads up to the ultimate strength of the concrete core. This decrease in load probably was due to two causes: 1st, the backing off of the testing machine, and 2d, to the plastic (inelastic) deformation. This backing could be seen in the reversal of the driving shaft upon stopping the machine after applying a load. An attempt was made to prevent this by leaving the clutch partly engaged after the load had been applied, but it is not certain that this purpose was fully accomplished. During the first tests there was some question as to what should be called the actual load under these conditions. So experiments were made on columns 8922 and 8907 to determine the effect of this dropping off of load and of reapplying the load up to its initial value on the longitudinal and lateral deformations. For this purpose, after the load had been raised to the desired value readings of the load were taken at short intervals and the load and the time recorded. At the same time strain gage readings on several longitudinal gage lines were taken, the time being recorded for each reading. The load-time curves and the deformation-time curves were then plotted on the same sheet, and in this way the effects of the dropping off and reapplication of load were readily seen. These results for a unit load of 1000 lb per sq. in. on the column are shown on page 27A. From these curves, it is seen that with the decrease in load there is a slight tendency toward an increase in longitudinal deformation. Upon the reapplication of the original load the longitudinal deformations showed a considerable increase. No determination was made of the relation between the increase in deformation and the amount of load added


120000
5
10
20
30
40
50
60
70
80
90
Time in minutes
110000
100000
Total Load on Column.
Load Reapplied
Load-Time Curve.
Corrected Instrument Readings
125
120
110
90
85
80
75
Gage Line 12
13
14
15
←.00022 in/in→
CURVES SHOWING
Variations in
INSTRUMENT-READINGS
WITH TIME
COLUMN 8922
Length 19'-8"
p = 4.48%
Ult. Load = 192000#

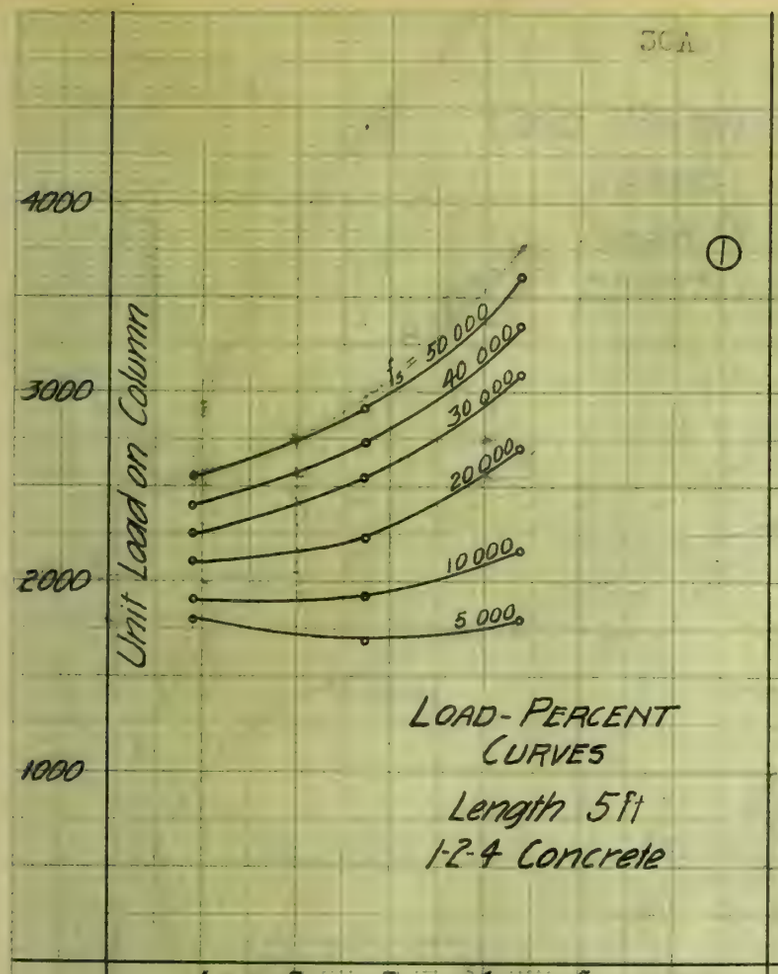


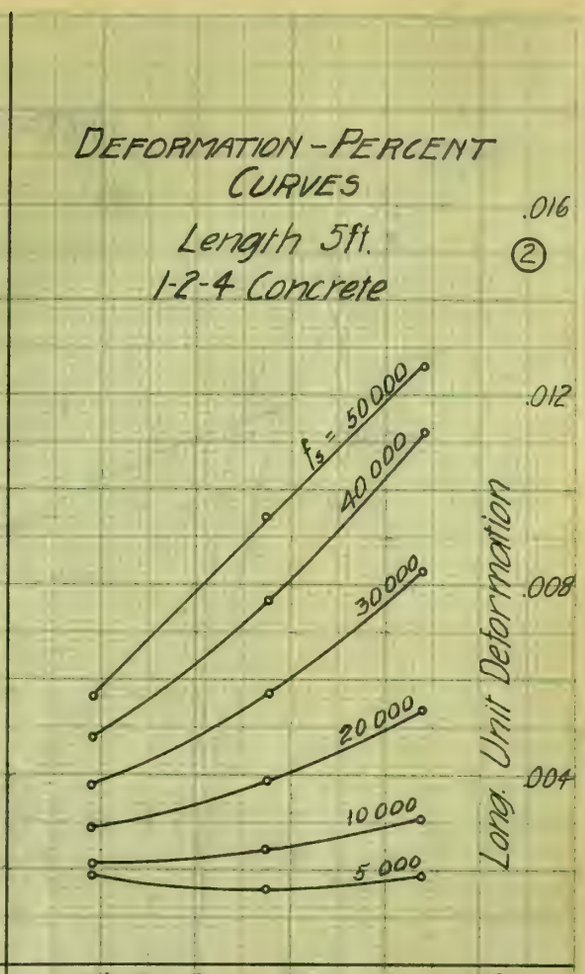
in bringing it up to its original value, but previous tests seem to indicate that this increase in deformation is the same as if a load equal to the amount of the added load were applied for the first time. That is, if the load P on a column should decrease successively by amounts V_1, V_2, V_3 and increments of load V_1, V_2, V_3 be reapplied, the total load on the column will be equal to P, but it seems that the deformation in the column would be the same as it would have been immediately after applying an original total load of $P + V_1 + V_2 + V_3$. The measurements discussed in the preceding paragraphs were taken on a 20-ft. column (NO. 8922) and the stress was so small that little information could be gathered on the effect of reapplication of load on the stress in the spiral. To determine the effect on the stress in the spiral of the dropping off and the reapplication of the load, it was necessary to take readings on shorter columns. So additional observations were made on 5-ft. columns of the stress in the spiral as soon as the load was applied the first time and later when the load had been raised to its initial value. From these it was found that the reapplication of load caused a very decided increase in the stress in the spiral while previous observations had shown that the dropping in load had no appreciable effect on the stress when the original load was not reapplied. In all tests made before these results had been obtained, the load was applied and then held constant by running the machine as fast as the load dropped for five minutes before starting reading. While taking readings the load was brought up to its initial value one or more times, the number depending upon the length of time required to take

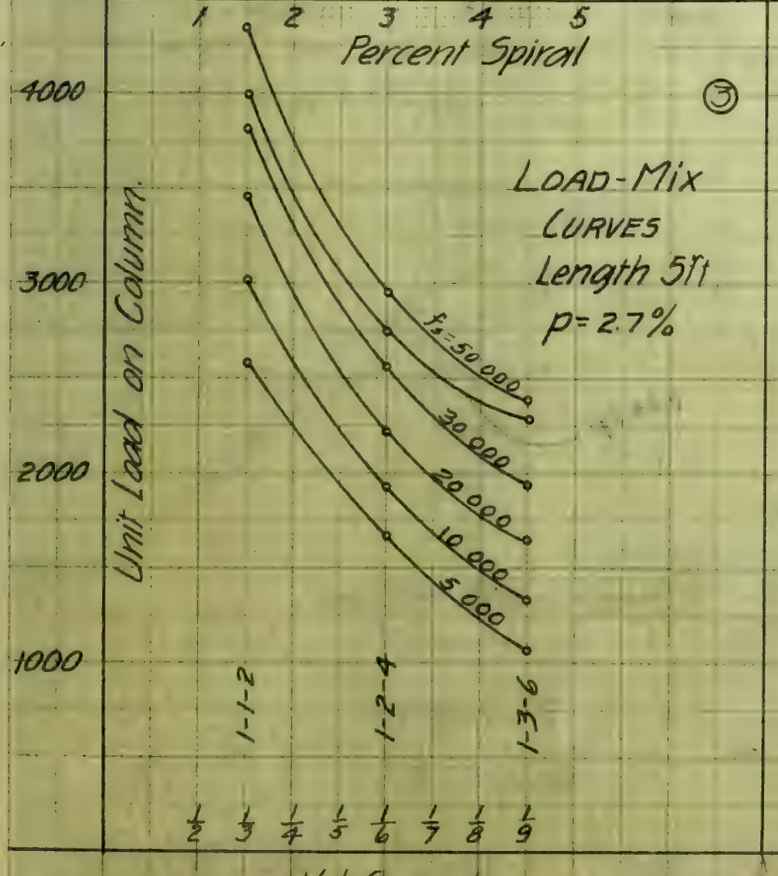
the reading. As a result of these tests, it was decided to bring the load up to the desired value and to disregard any decrease in load. The load for the series was taken as being the maximum load applied. This method was used for all columns tested except No. 8922, 8907 and 8916. For each series of readings, the actual load at the end of each set of readings was generally recorded, but no use has been made of this information.

The question as to what should be called the actual load on the column is an important one. It is probable that to produce a deformation in a column requires some time. So if the load is applied at a relatively high rate of speed and the maximum load thus applied is taken as the actual load on the column, then the question might be asked if the deformation produced by this load might not also have been produced by some lower dead load which was able to follow up any change in length. It seems reasonable to expect that such would be the case. If this is true, then the ultimate strengths of the columns as tested in a machine are higher than would be obtained if these were subjected to a dead load. This means that the apparent increase in strength per cent or one per cent of spiral is higher than it should be. Just what effect the variation in the per cent of spiral would have upon the relation between the strengths as determined by a testing machine and by a dead load is entirely unknown.

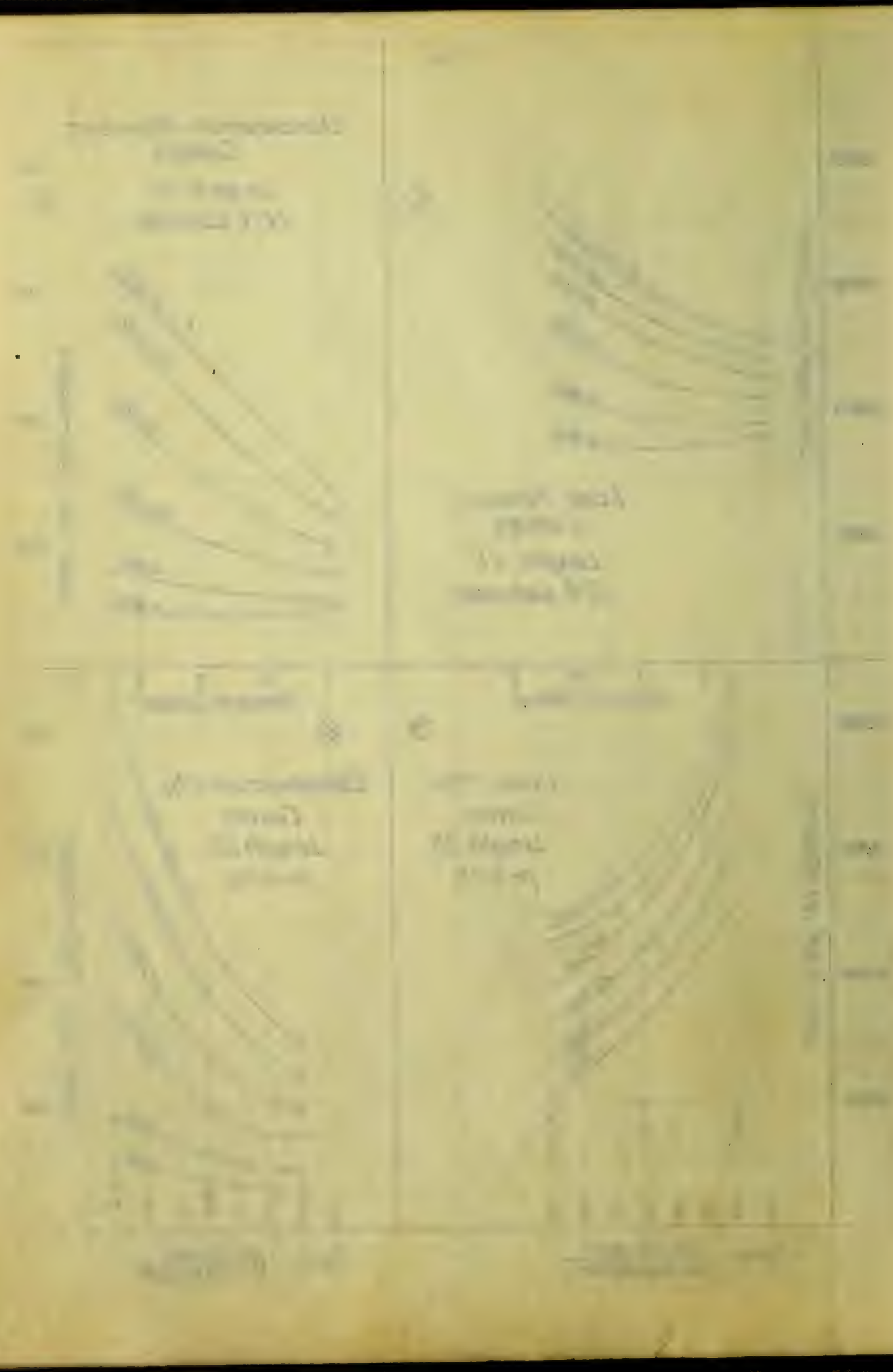
Table IV, which gives the average unit load on the columns and the longitudinal unit deformations for various stresses in the spiral, contains some very important results of the tests. These results have been plotted on sheets 30A to 30G in

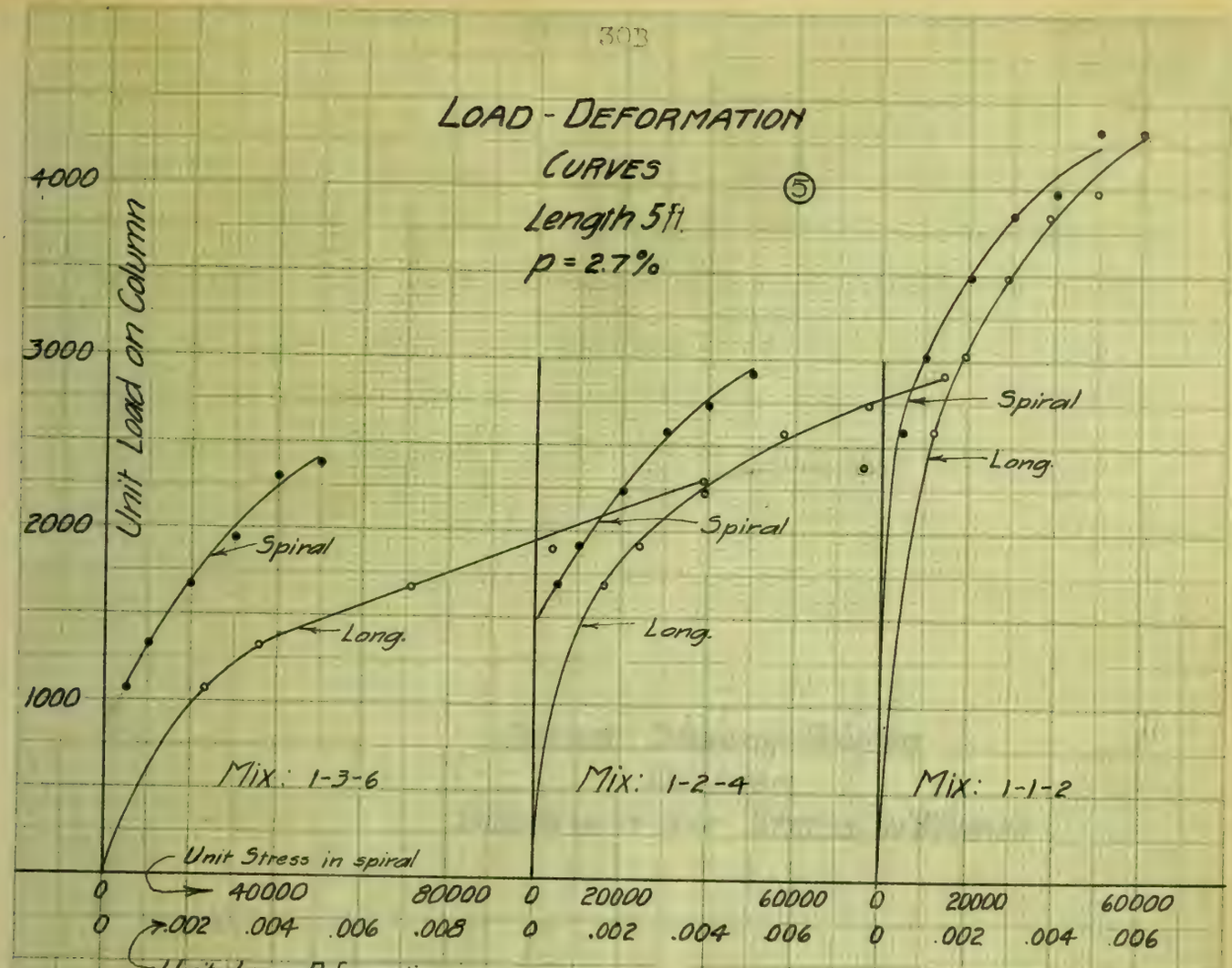

4000
3000
2000
1000
Unit Load on Column
f_s = 50 000
40 000
30 000
20 000
10 000
5 000
①
LOAD - PERCENT CURVES
Length 5ft
1-2-4 Concrete

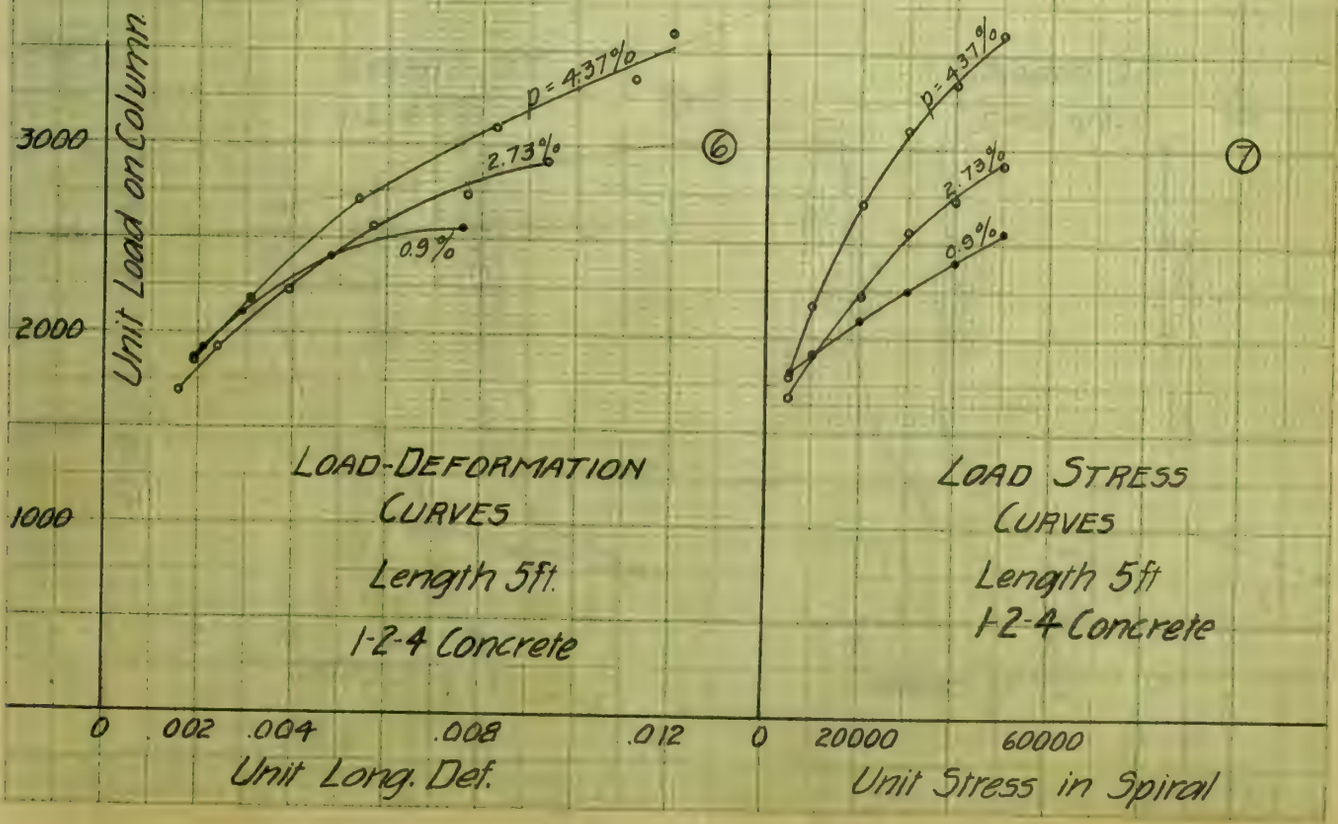

DEFORMATION - PERCENT CURVES
Length 5ft.
1-2-4 Concrete
②
.016
.012
.008
.004
Long. Unit Deformation
f_s = 50 000
40 000
30 000
20 000
10 000
5 000


1 2 3 4 5
Percent Spiral
③
4000
3000
2000
1000
Unit Load on Column.
LOAD - MIX CURVES
Length 5ft
p = 2.7%
f_s = 50 000
30 000
20 000
10 000
5 000
1-1-2
1-2-4
1-3-6
1/2 1/3 1/4 1/5 1/6 1/7 1/8 1/9
Ratio: Vol. Cement / Vol. Aggregate


1 2 3 4 5
Percent Spiral
④
.016
.012
.008
.004
Long. Unit Deformation.
DEFORMATION - MIX CURVES
Length 5ft.
p = 2.7%
f_s = 50 000
40 000
30 000
20 000
10 000
5000
1-1-2
1-2-4
1-3-6
1/2 1/4 1/5 1/7 1/8 1/10
Ratio: Vol. Cement / Vol. Aggregate

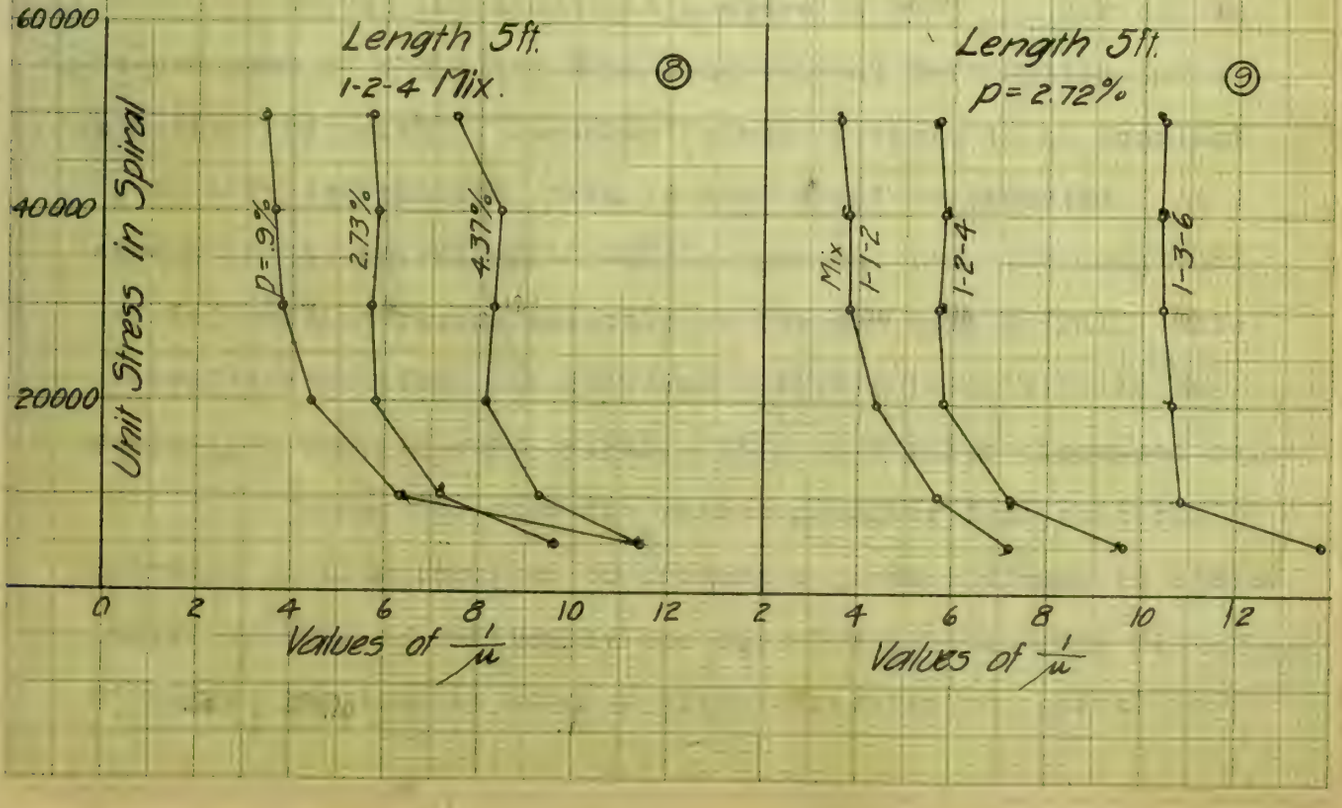



LOAD - DEFORMATION
CURVES
Length 5ft.
p = 2.7%
⑤
4000
3000
2000
1000
Unit Load on Column
Spiral
Long.
Mix: 1-3-6
Mix: 1-2-4
Mix: 1-1-2
Unit Stress in spiral
0
40000
80000
60000
20000
.002
.004
.006
.008
Unit Long. Deformation


3000
2000
1000
Unit Load on Column
p = 4.37%
2.73%
0.9%
⑥
⑦
LOAD-DEFORMATION
CURVES
Length 5ft.
1-2-4 Concrete
LOAD STRESS
CURVES
Length 5ft
1-2-4 Concrete
0
.002
.004
.008
.012
20000
60000
Unit Long. Def.
Unit Stress in Spiral



Curves Showing Relation Between Values of $\frac{1}{\mu}$ and Stress in Spirals





order to bring out the results more plainly.

Curves (1) show that the stress of 5,000 lb. per sq. in. in the spiral is produced for all per cents at practically the same load. This is probably only roughly true, for the estimation of the load at which this stress occurs, depends a great deal upon the judgment of the one studying the curves. For higher stresses, as the percent of spiral increase, the increase in load per percent increase in spiral becomes larger.

The term Poisson's ratio is used in this thesis to mean the ratio of the unit deformation in the spiral, to the longitudinal unit deformation. It is understood that the term Poisson's ratio ordinarily is used to denote this ratio for elastic homogenous materials, but it is convenient to use it in this thesis as defined above.

Curves (2) show that a stress of 5000 lb. per sq. in. is produced at about the same longitudinal deformation for all amounts of spiral. Assuming Poisson's ratio to be constant up to this deformation, this is what might be expected. At a stress in the spiral of 50,000 lb. per sq. in., the longitudinal deformation varies directly as the per cent spiral. This evidently means that the relation called Poisson's Ratio depends upon the per cent spiral. This is further discussed below.

Curves (3) show the rather peculiar fact that the increase in load required to produce a given increase in stress in the spiral is practically the same for all concrete mixtures. Of course the load at which a given stress in the spiral is

reached depends upon the mixture. For low stresses in the spiral this load varies directly about as the variation in the ratio of the volume of cement to the volume of aggregate.

The relation between the longitudinal unit deformation and the stress in the spiral for various mixtures is shown in curves (4). It should be noticed that for stresses above 10,000 lb. per sq. in., for a given mixture the value of Poisson's ratio is a constant. This is better shown by the curves page 30C. On page 30B there are a few things to be noticed. For the 1-3-6 mixture and for the 1-2-4 mixture where p = 2.73%, after the spiral begins to act it takes stress almost directly in proportion to the change in load. The richer the concrete or the higher the per cent of spiral, the more the load-stress curve departs from a straight line. It should be noted that in the case of the 1-1-2 mixture the spiral begins to take stress very gradually while it starts more suddenly for the other mixtures. This probably is due to the fact that in the leaner mixtures there are many fine air pores, and the first result of the longitudinal deformation is to fill these pores before the lateral deformation becomes appreciable. In fact, from an examination of curves (9), we see that for a stress in the spiral of 40,000 lb. per sq. in. the value of Poisson's ratio varies as $\frac{1}{3.8}$, $\frac{1}{5.8}$, and $\frac{1}{10.4}$ for 1-1-2, 1-2-4, and 1-3-6 mixtures. Multiplying each by the corresponding value of the ratio of volume of aggregate to the volume of the cement we have

$$\frac{1}{1.37}, \quad \frac{1}{.97}, \text{ and } \frac{1}{1.15} \qquad \text{---------- (A)}$$

Roughly, then, Poisson's ratio varies directly as the per cent of cement in the mixture. At f_s = 5,000 lb. per sq. in., the ratio corresponding to those given as A are

$$\frac{1}{1.27}, \frac{1}{.97}, \text{ and } \frac{1}{1.15} \quad \text{---------- (B)}$$

That is, for the two leaner mixes Poisson's ratio varies directly as the above ratio, but this is not true for the richest mixture. It may be that at some point between the 1-2-4 and 1-1-2 mixtures, the voids in the sand are completely filled and for any further increase in cement the value of Poisson's ratio is influenced by the Poisson's ratio of the cement alone. This might be an interesting point for further investigation.

The following results are readily obtained by a consideration of curves (4) page 30A.

1. 1-1-2 Concrete. 2.72% spiral.

Average change in deformation, $\Delta\lambda$, for 10000 lb. per sq. in. change in stress in spiral = .00102 in. per in.

$$\mu = \frac{1}{3.06}$$

For 1-1-2, $\mu' = \frac{1}{3.06} \times 2.72 = \frac{1}{1.12}$

2. 1-2-4 Concrete. 2.73% spiral.

Limits in f_s, 10,000 to 50,000.

$\Delta\lambda = .00175$. $\mu = \frac{.000333}{.00175} = \frac{1}{5.25}$

$\mu' = \frac{1}{5.25} \times 2.73 = \frac{1}{1.92}$

1-2-4 Concrete, p = 4.37%, f_s 10,000 - 40,000

$\Delta\lambda = .00270$. $\mu = \frac{.000333}{.00272} = \frac{1}{8.10}$

$\mu' = \frac{1}{8.10} \times 4.37 = \frac{1}{1.85}$

Average for p = 2.73% and 4.37% = $\frac{1}{1.88}$

3. 1-3-6 Concrete. p = 2.72%

f_s 10,000 - 50,000

$\Delta\lambda = .0035$

$\mu = \frac{.000333}{.0035} = \frac{1}{10.5}$

$\mu' = \frac{1}{3.87}$

Considering the columns made of 1-2-4 concrete we find that Poisson's ratio varies with the per cent reinforcement, being smallest for the largest per cent. For the two largest per cents we find that the value denoted by μ' is very nearly a constant.

Considering curves (8), page 300, we find that for p = 4.37% the average value of $\frac{1}{\mu}$ is 8.2, for p = 2.73% $\frac{1}{\mu}$ = 5.8 and for p = .9% $\frac{1}{\mu}$ = 3.8. Dividing each of these by the corresponding per cent of spiral we get 1.87, 2.13, and 4.22. That is for the two highest per cents of reinforcement the value of Poisson's ratio varies inversely about as the per cent of spiral. This means that for a given longitudinal deformation the total lateral pressure is constant and independent of the per cent of spiral.

It is probable that the reason this is not true for the columns having small per cents of spiral is that at the load at which the stress in the spiral reaches this value the concrete still has enough strength to carry part of the load. It is possible that the above relation is true for the columns

having .9% spiral for very high lateral stresses.

The following facts are found to be true for the 5-ft. columns.

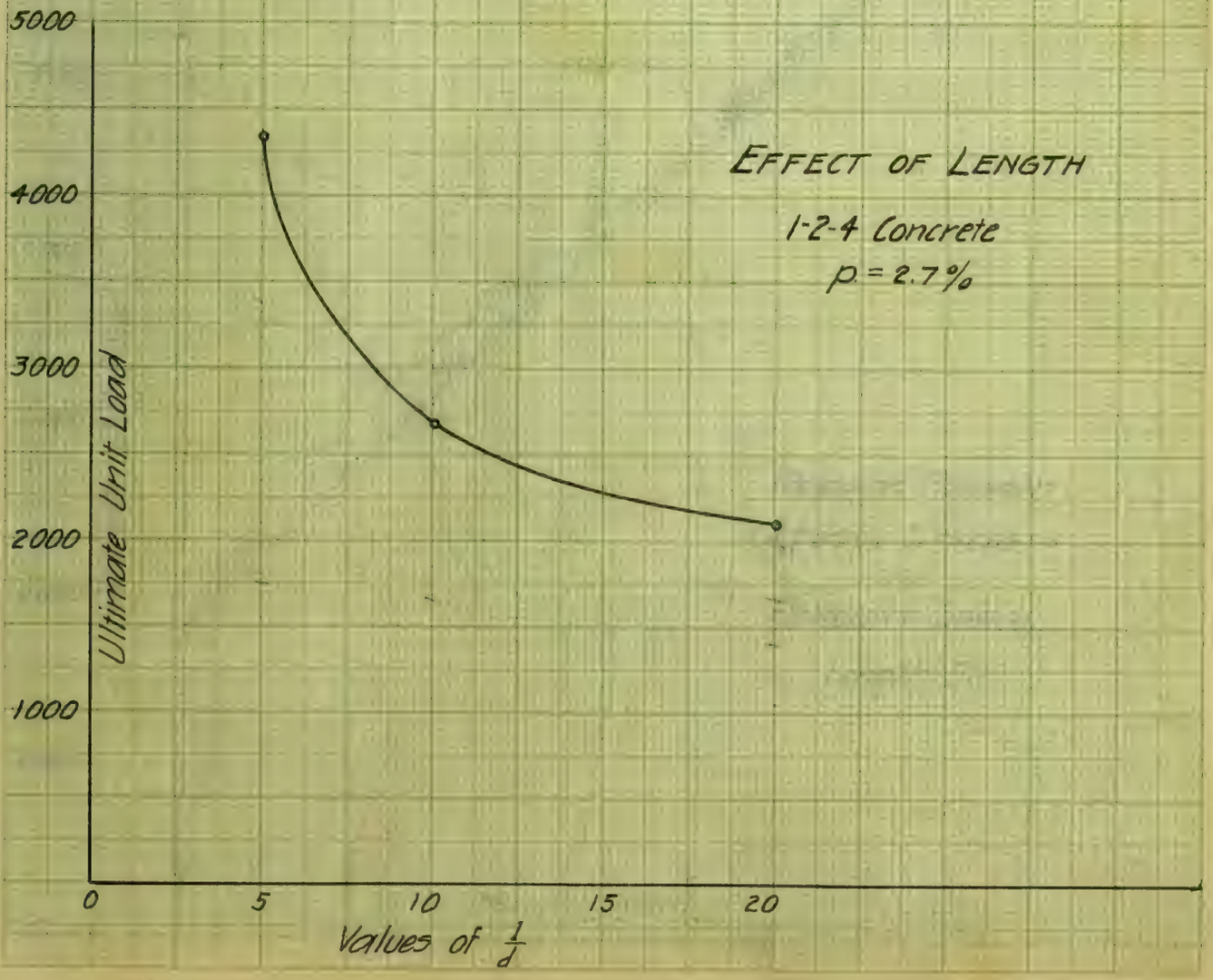
To produce a stress in the spiral of 20,000 lb. per sq. in. requires a load 5.7% higher where p = 2.74% and 28.6% higher where p = 4.37% than when p = 0.9%. For a stress in the spiral of 50,000 lb. per sq. in. the increase in load is 14.1% for p = 4.37% over that required for p = 0.9%.

To produce a stress in the spiral of 50,000 lb. per sq. in., the longitudinal unit deformation must be increased 40% for p = 2.74% and 89% for p = 4.37% over that required where p = 0.9%.

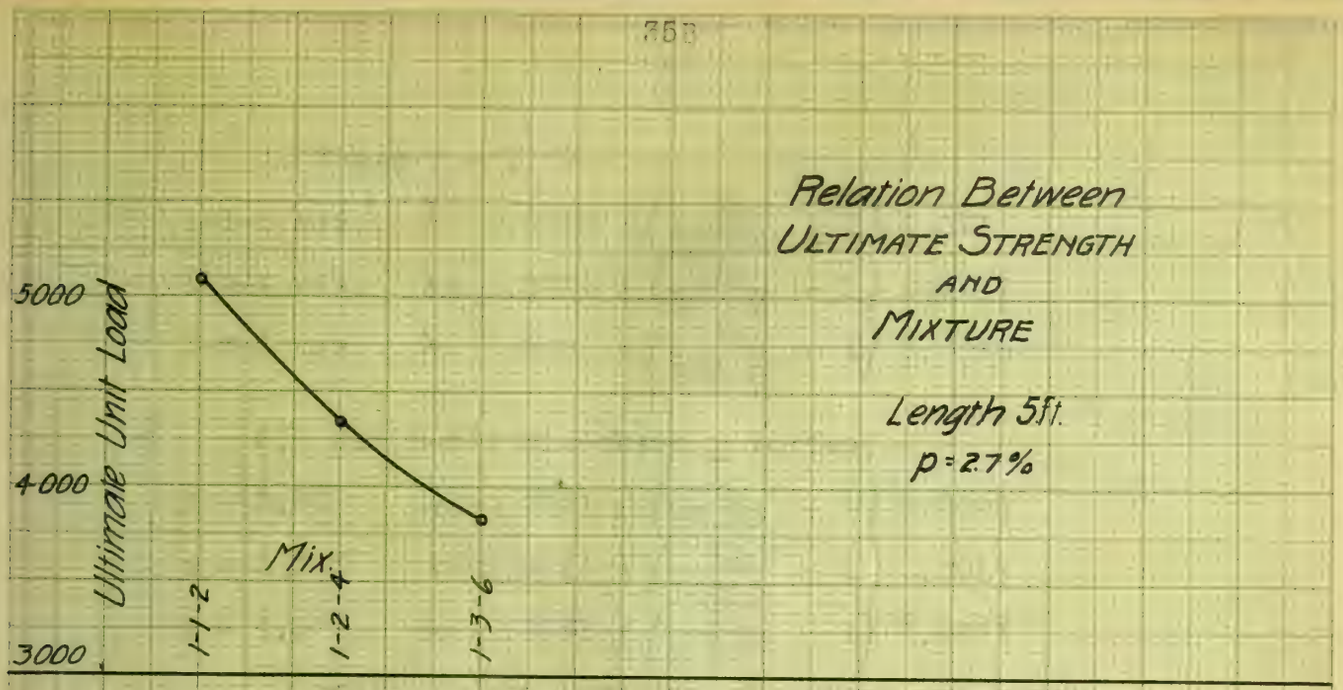
Considering the 5-ft. columns where p = 2.7% we see that the value of the longitudinal unit deformation at values of f_s of 40,000 and 50,000 lb. per sq. in. varies inversely as the variation in the ratio of the volume of cement to the column of aggregate. That is, to produce a stress of 50,000 lb. per sq. in. in the spiral of a 1-3-6 column requires three times the deformation required to produce this stress in the spiral of a 1-1-2 column , and in the 1-2-4 columns the deformation must be twice that in the 1-1-2 columns.

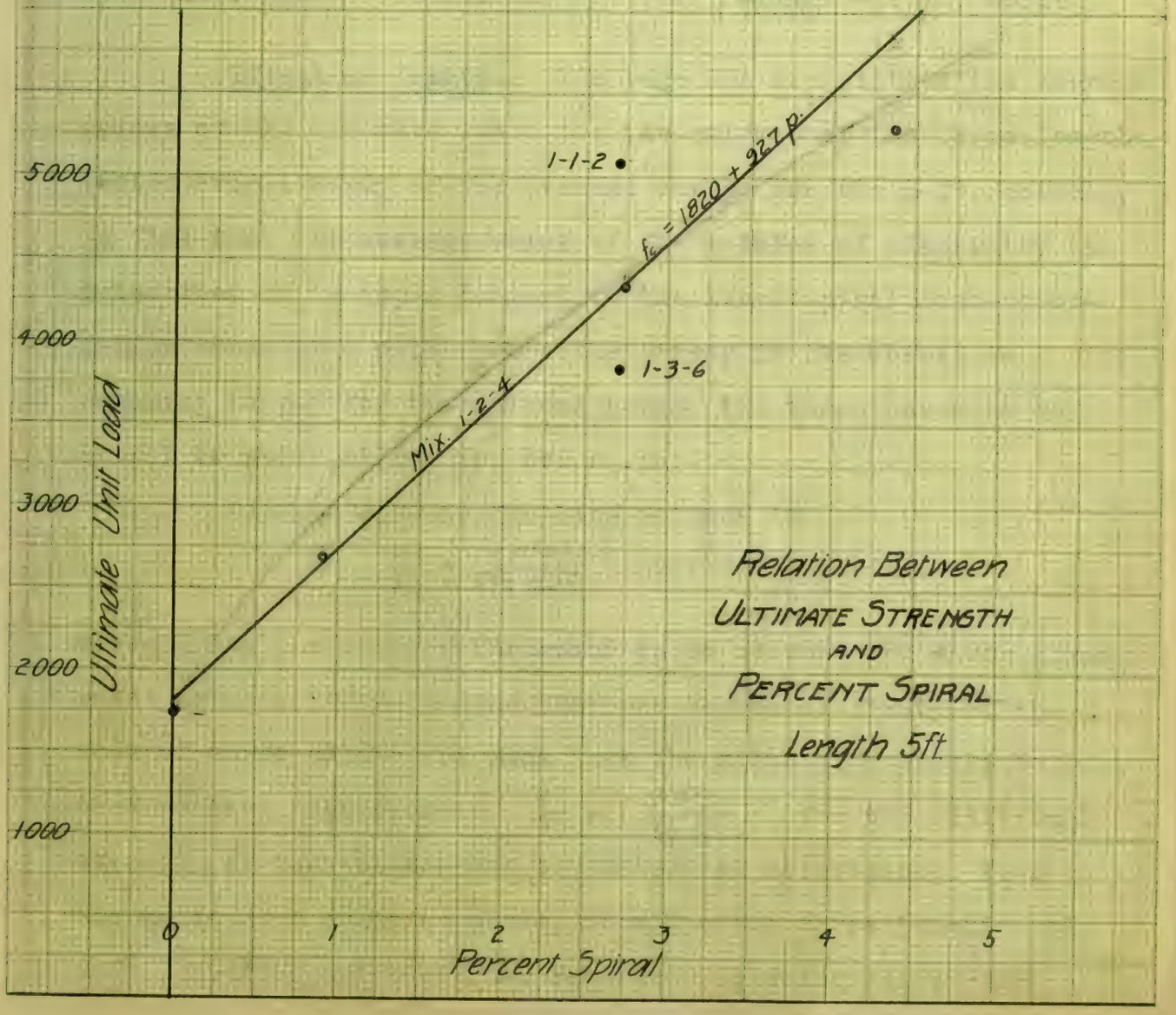
Relation between longitudinal unit deformation (λ) and f_s the stress in the spiral, for values of f_s between 10,000 and 50,000 lb. per sq. in. These are derived from curves page 30A.

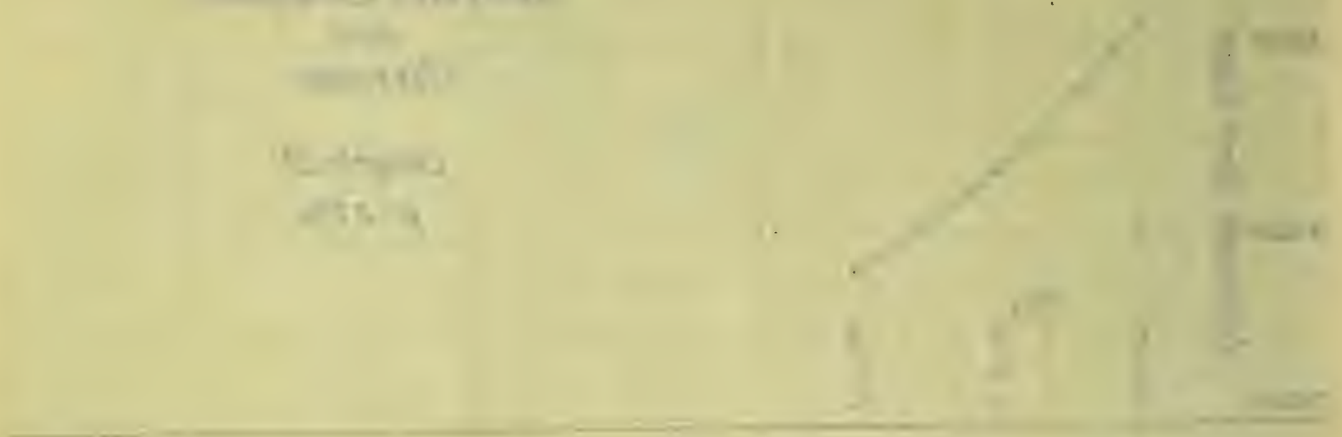
are given on the next page.


5000
4000
3000
2000
1000
Ultimate Unit Load
0
5
10
15
20
Values of $\frac{1}{d}$
EFFECT OF LENGTH
1-2-4 Concrete
$p = 2.7\%$




Relation Between
ULTIMATE STRENGTH
AND
MIXTURE
Length 5ft.
p = 2.7%
Ultimate Unit Load
5000
4000
3000
Mix.
1-1-2
1-2-4
1-3-6


Ultimate Unit Load
5000
4000
3000
2000
1000
1-1-2
$f_c = 1820 + 927p$
1-3-6
Mix. 1-2-4
0
1
2
3
4
5
Percent Spiral
Relation Between
ULTIMATE STRENGTH
AND
PERCENT SPIRAL
Length 5ft.





1. Where p = 2.7%

1-1-2 mix. $\lambda = 0.0019 + \left(\frac{f_s}{10000} - 1\right) 0.001$

1-2-4 mix. $\lambda = 0.0034 + \left(\frac{f_s}{10000} - 1\right) 0.0017$

1-3-6 mix. $\lambda = 0.0056 + \left(\frac{f_s}{10000} - 1\right) 0.0035$

2. For 1-2-4 mix where p varies,

p = 0.9%, $\lambda = 0.0021 + \left(\frac{f_s}{10000} - 1\right) 0.0009$

p = 2.74% $\lambda = 0.0024 + \left(\frac{f_s}{10000} - 1\right) 0.0017$

p = 4.37%, $\lambda = 0.0031 + \left(\frac{f_s}{10000} - 1\right) 0.0037$

Combining the last two equations, we have:

$$\lambda = .00088p + .00043\ (p - 2.7) + \left(\frac{f_s}{10000} - 1\right) .00062p$$

Effect of Length.- On page 35A are plotted the average values of the ultimate loads for the columns of the three lengths tested. From a study of the average curves for the 5-ft. columns, we find that the average value of the modulus of elasticity (as determined by taking a tangent to the longitudinal load-deformation curve at a point where the stress in the spiral is becoming large) for the columns having the three percents of spiral is about 72,000 lb. per sq.in.

Euler's formula for long columns is

$$\frac{P}{A} = \frac{K\pi^2 E}{(l/r)^2}$$

where K has the value 1 for round ended columns and 4 for fixed ended columns. If we assume that the degree of fixity of the ends of these columns is such that the value of K should be 3, then we have the formula $\frac{P}{A} = \frac{3\pi^2 E}{(l/r)^2}$ for the additional strength of the columns due to the spiral reinforcing. Taking the value of E as given above, then for the three lengths of 5-ft., 10-ft., and 20-ft, we have the following values for

$\frac{P}{A}$, 5380 , 1320, 330 lb.per sq.in. If it is assumed that this formula does not apply to the 5ft. columns, then these values may be approximately correct. But from a study of the average curves, as well as from theoretical considerations, it seems that the value of E is not a constant, but depends upon the length of the column. With this in mind, it hardly seems that the added strength can be represented by a formula of the form of Euler's. While variations in the amount of spiral have little effect upon the strength of the 20-ft. columns, they certainly do affect the strengths of the 10-ft. and 5-ft. columns, and it seems that any formula for calculating the added strength should take account of these facts.

Effect of Amount of Spiral.- The relation between the ultimate strength of the column and the amount of spiral is shown for the 5-ft. columns of 1-2-4 concrete by the lower curve on page 35B. From this curve we see that 1% of spiral adds an average of 927 lb. per sq. in. to the strength of the column. This value is somewhat lower than that usually found.

From Table VI, page 219, we find the ultimate strengths of the columns of 1-1-2, 1-2-4, and 1-3-6 mixtures to be 5080, 4400, and 3810 lb. per sq. in., for 2.7% spiral. Taking the strengths of the concretes as being 3400, 1900, and 800 lb. per sq. in., we have the added strengths 1680, 2500, and 3010 lb. per sq. in. For 1% these are 624, 927, and 1120 lb. per sq. in. It may seem strange that the rich concretes show less increase per percent than do the poorer ones, but when it is remembered that the value of Poisson's ratio is higher at all loads for rich than for lean concretes, this seems reasonable. The discuss-

ion on page 31 also has a bearing on this point.

From a study of the curves on page 30E, the following relation was found to be true for the 5-ft. columns having 2.72% of reinforcement: Taking those parts of the load-deformation curves between the origin and the points at which the stress in the spirals is equal to 50 000lb. per sq. in., we find that the areas under the curves for the 1-1-2 and the 1-2-4 concretes are equal, while the area under the curve for the 1-3-6 concrete is about 20% higher.

7.- Conclusions.- The following conclusions are based upon the study of the data of the columns and may not apply to columns of other sizes and made from other aggregates.

1.- The value of the initial modulus of elasticity of the column does not depend upon the amount of spiral reinforcement, but for any amount it is somewhat less than that for plain concrete.

2. The ultimate strength of the 5-ft. columns depends upon the amount of spiral and upon the mixture. It seems that the variation in strength of the concrete of the individual columns of a given mix, as measured by the strength of the cylinders, does not have an appreciable effect upon the ultimate strength of the column.

3. The ultimate strength of the 5-ft. and 10-ft. columns depends upon both the strength of the concrete and the amount of spiral, but the ultimate strength of the 20-ft. columns depends only upon the strength of the concrete and not upon the amount of spiral.

4. The load required to produce a stress in the spiral of 5 000-lb. per sq. in. in the 5-ft. columns is practically independent of the amount of spiral.

5. The longitudinal unit deformation required to produce a stress in the spiral of 5 000-lb. per sq.in. in the 5ft. columns is practically independent of the amount of spiral.

6. For a stress in the spiral of from 40 000 to 50 000-lb. per sq. in. the longitudinal unit deformation varies directly with the variation in the amount of spiral. but it does not approach zero as the amount of spiral approaches zero.

7. To produce a given change in stress in the spiral requires practically the same change in unit load for all concrete mixes.This is true for the 5-ft. columns having 2.7% of spiral.

8. Poisson's ratio is a constant for columns of a given mix and having a given amount of spiral for all stresses in the spiral between 10 000 and 50 000-lb. per sq. in.

9. After the spiral begins to take stress, the load-stress curve is a straight line for columns of 1-3-6 concrete having 2.7% spiral and for columns of 1-2-4 concrete having 0.9% spiral.

10. In columns of rich concrete the spirals begin to take stress more gradually than in those of poor concrete. The load at which the stress in the spiral reaches a given low value is a smaller proportion of the ultimate strength of the concrete alone for rich concrete than for lean concrete. . At low loads Poisson's ratio is larger for rich concrete than for lean concrete.

11. For the columns made of 1-2-4 concrete and having

the two highest percents of spiral, the total lateral pressure on the columns due to the stress in the spiral depends only upon the longitudinal unit deformation and is independent of the amount of the spiral.

CURVES

Page

Stress–deformation curves for steel in spirals . . 40 – 43

Load–Def. curves for cylinders 44 – 47

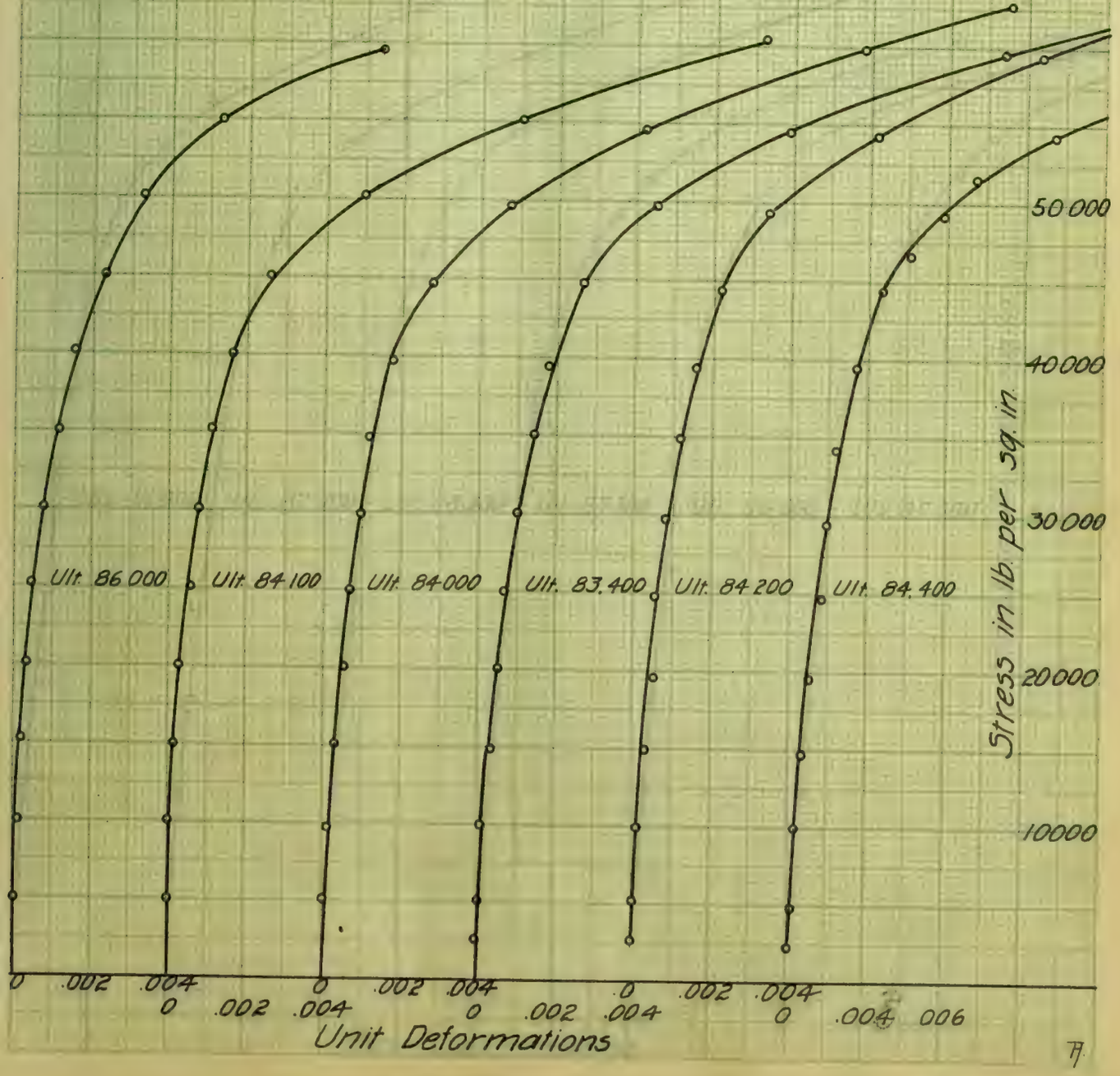
Load–deformation curves for all gage lines 48 –152

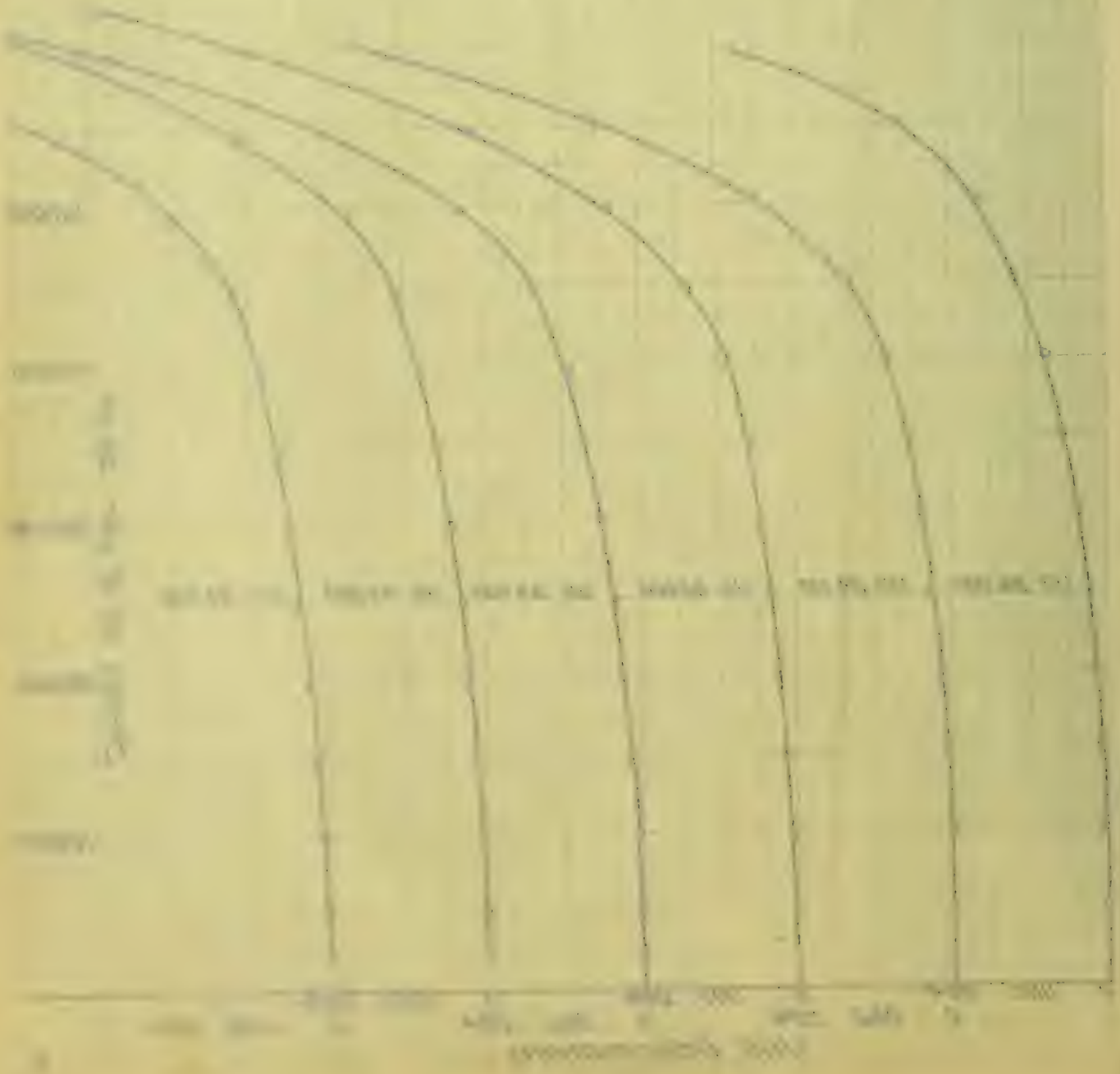
Distribution curves 177 –179

Average curves 180 –199

Stress-Deformation Curves for Steel in Spirals

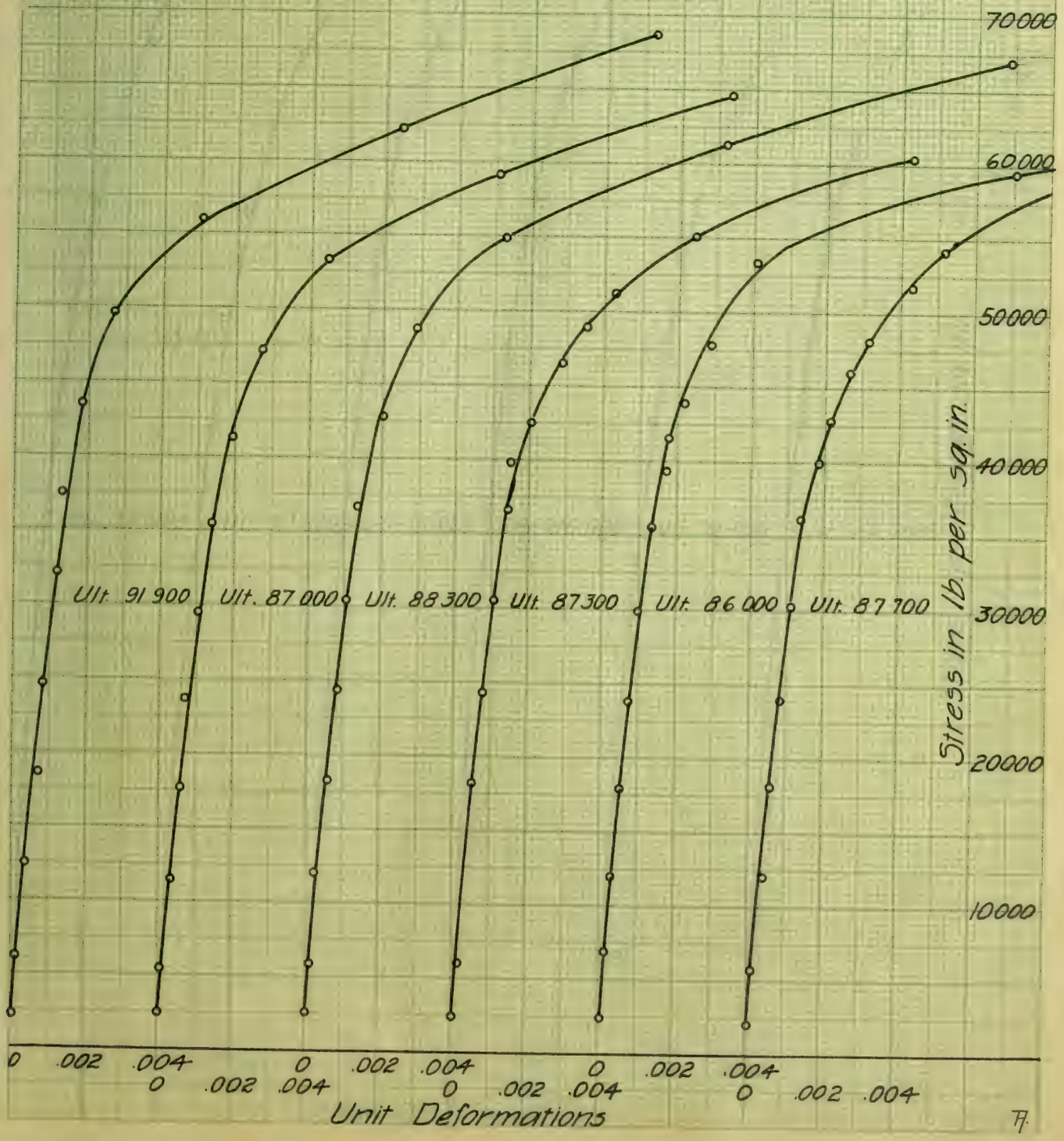
Steel ½ in. Diam.

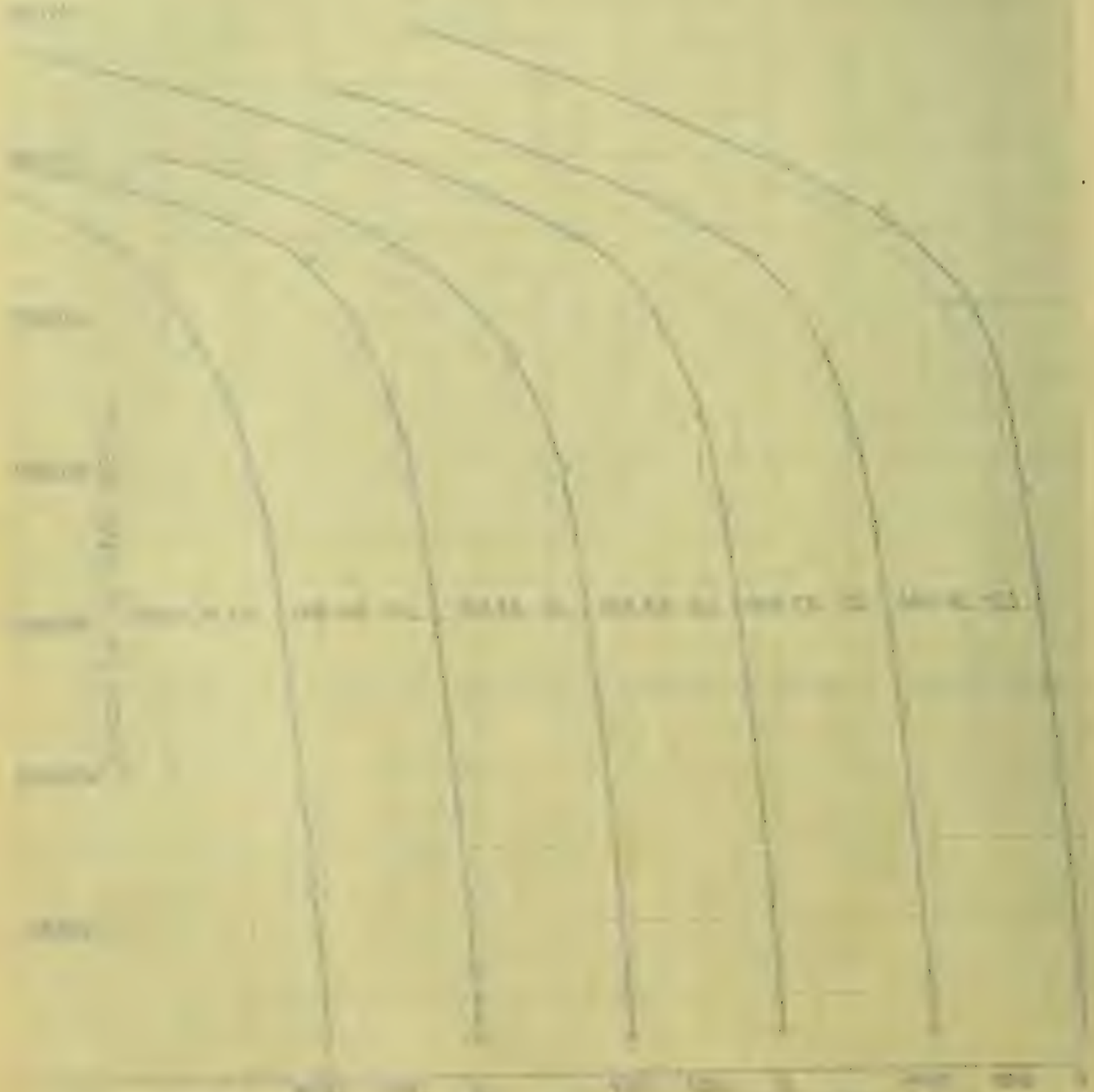




Stress-Deformation Curves for Steel in Spirals

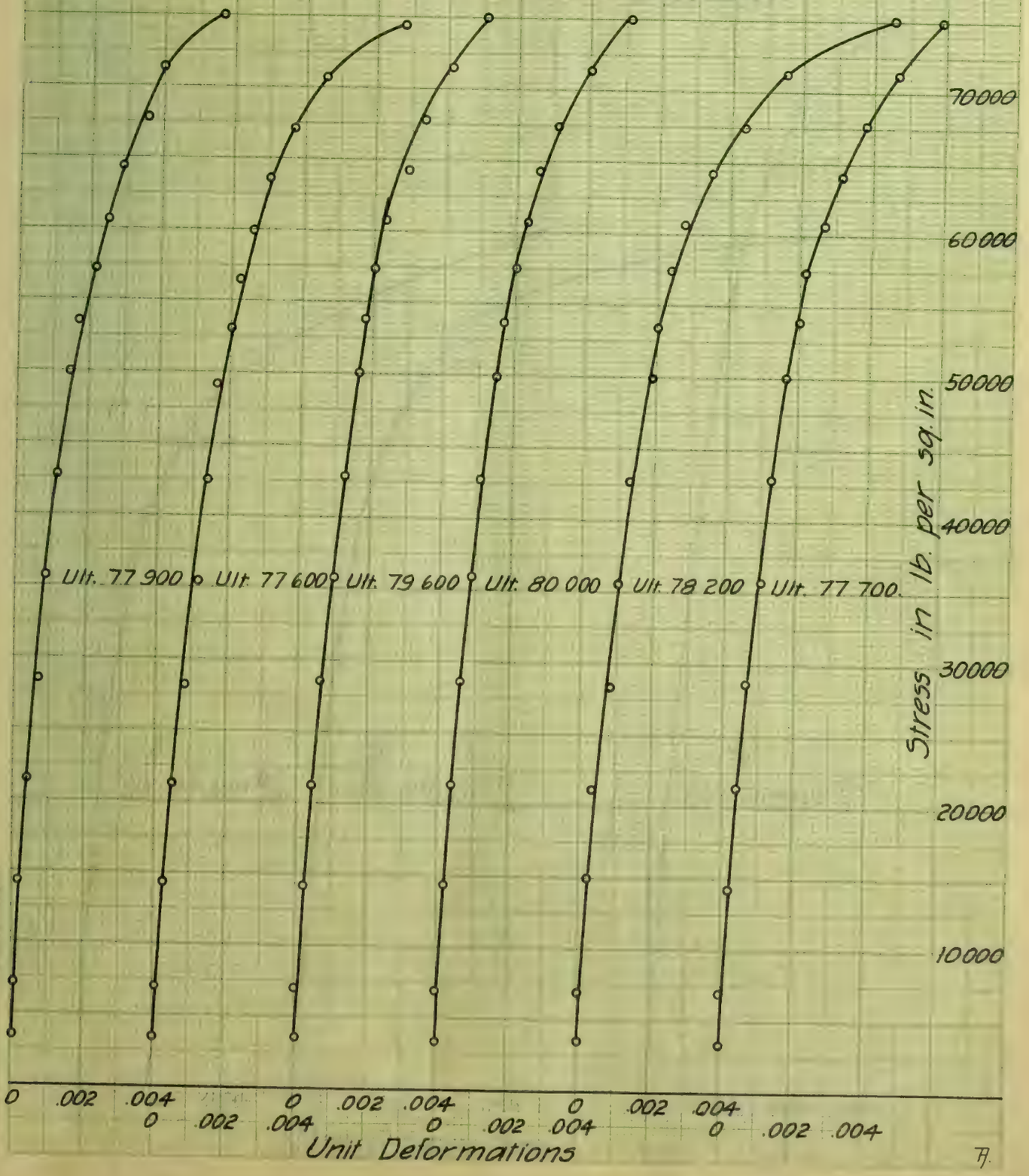
Steel $\frac{5}{16}$" Diam.



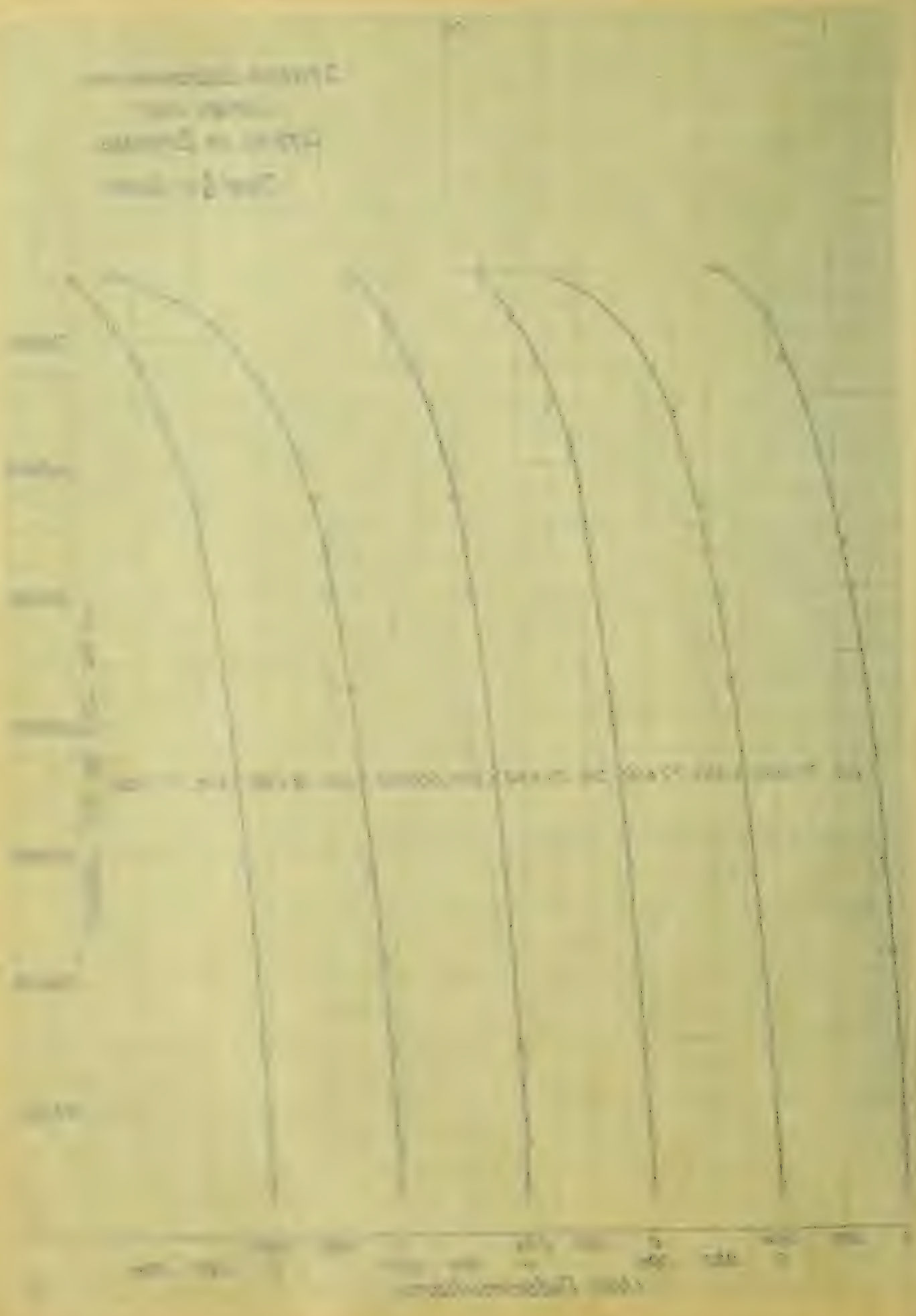


Stress-Deformation Curves for Steel in Spirals

Steel $\frac{3}{16}$ in. Diam.

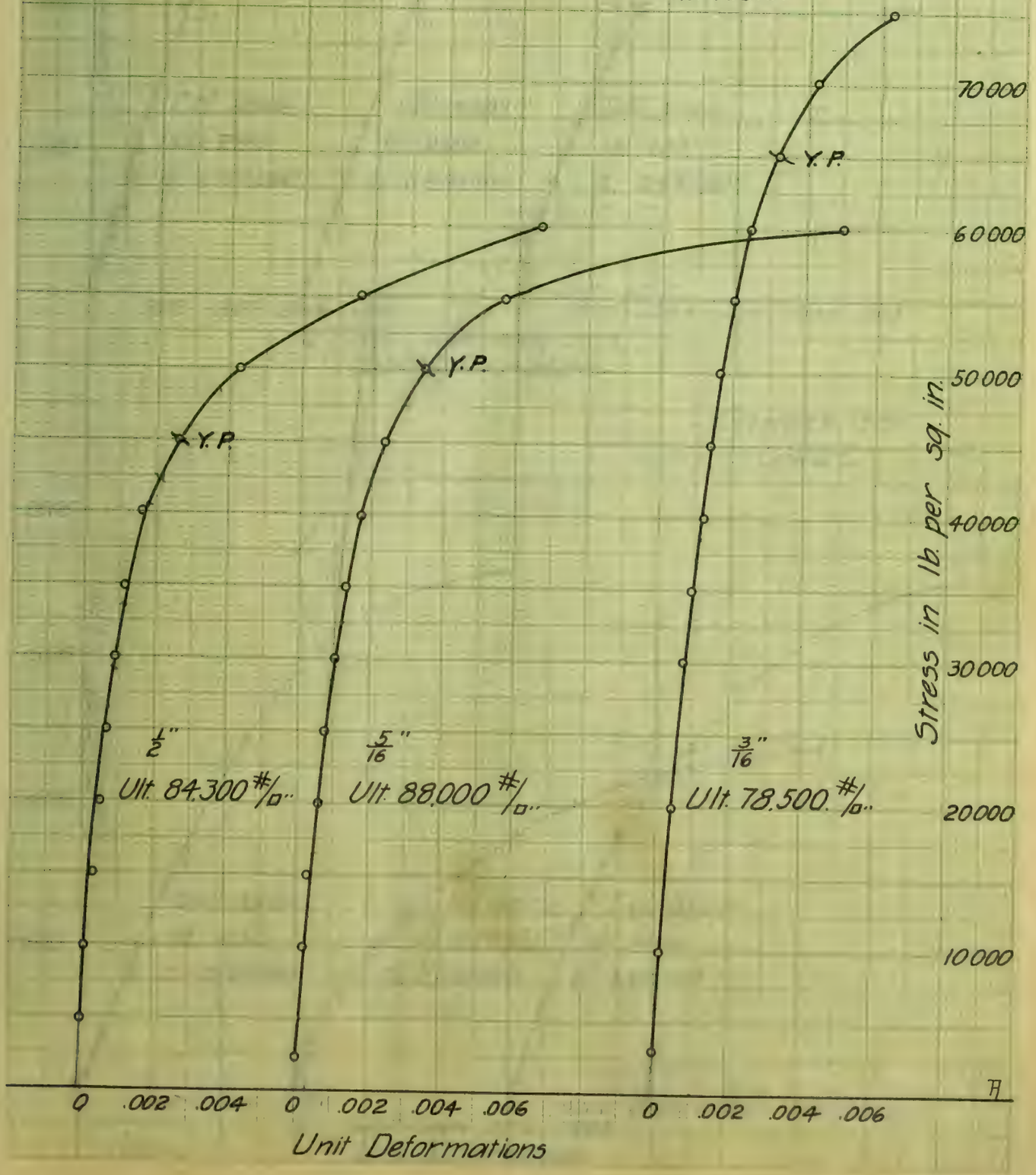


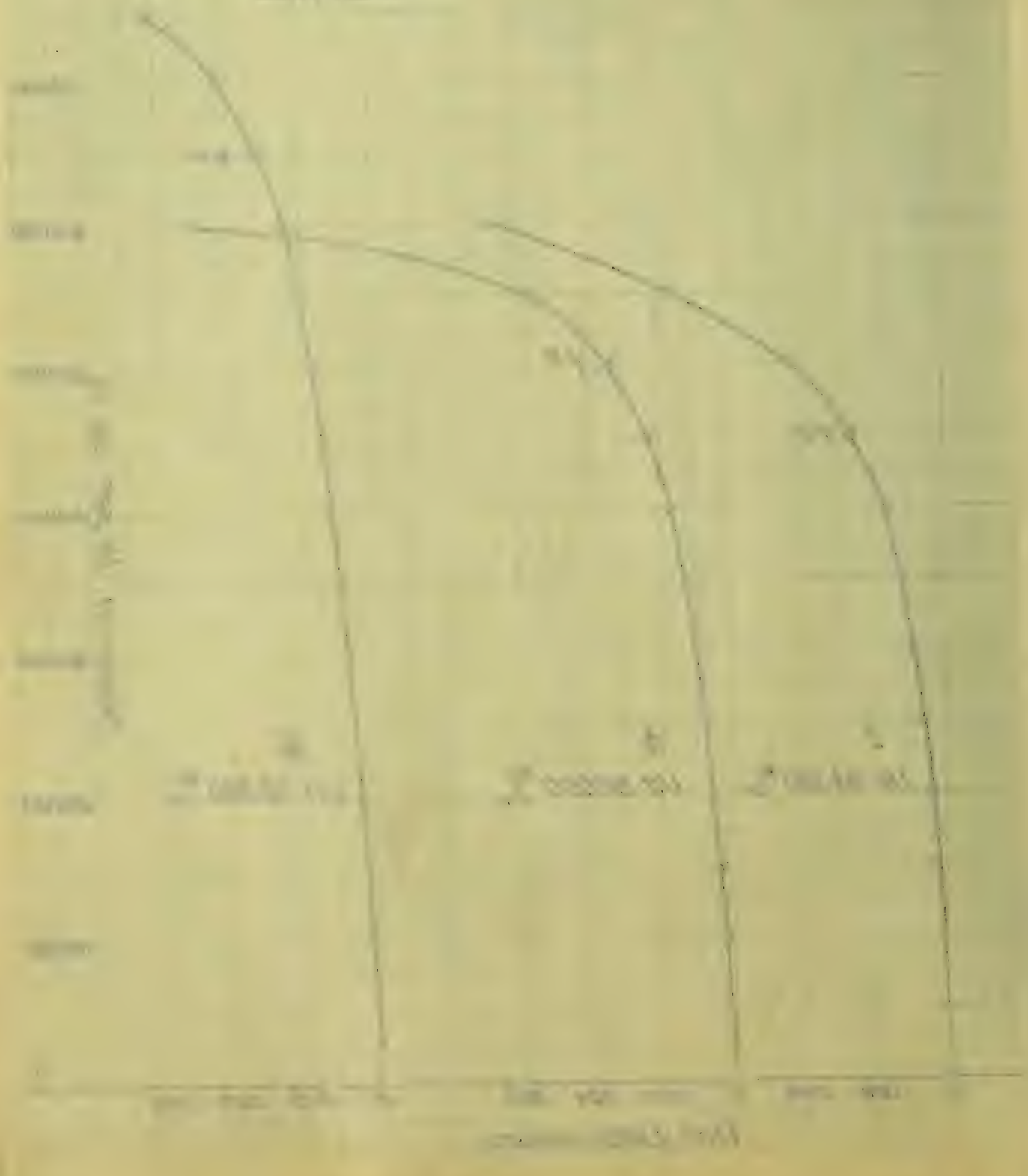
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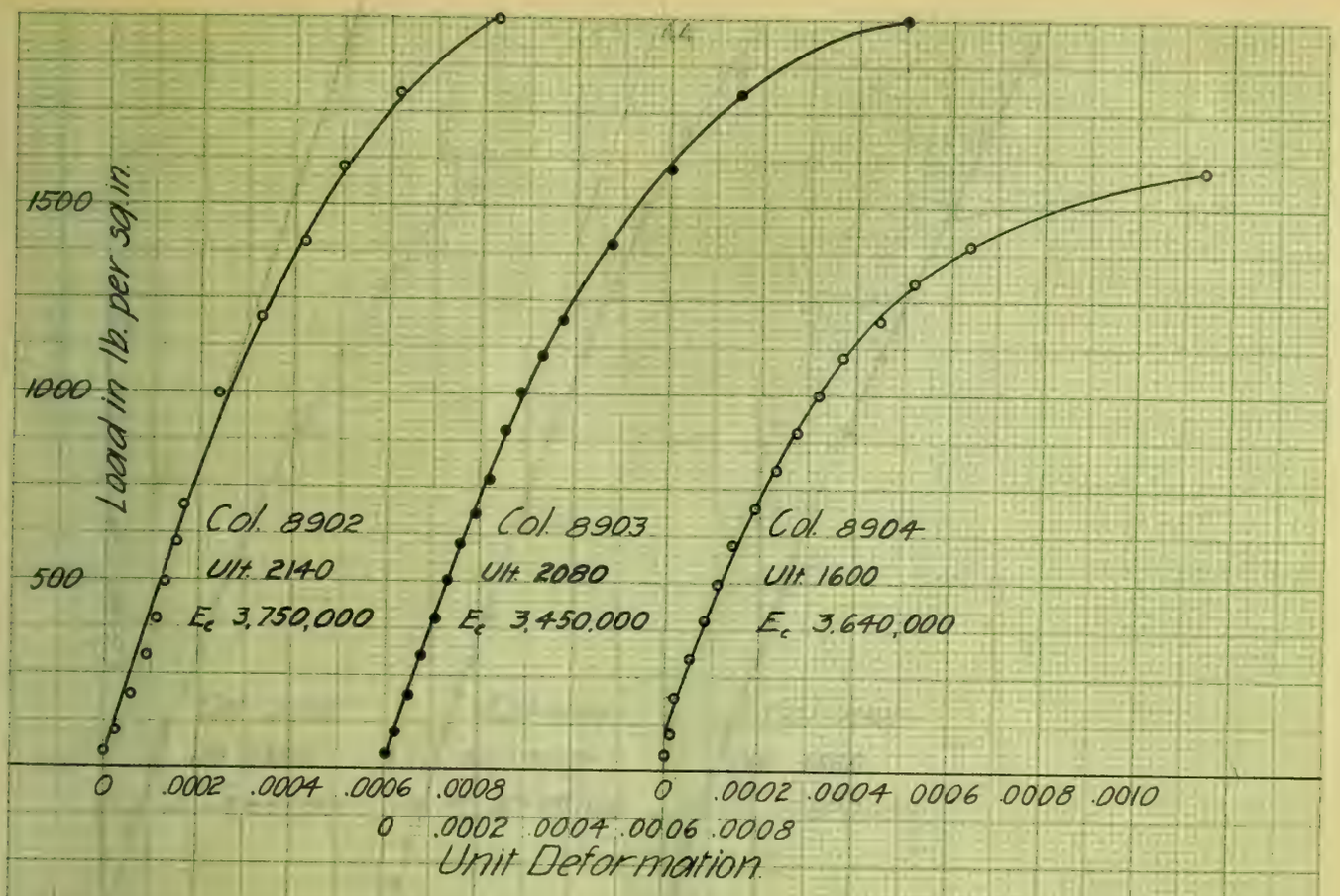


Average Stress - Deformation Curves for Steel in Spirals

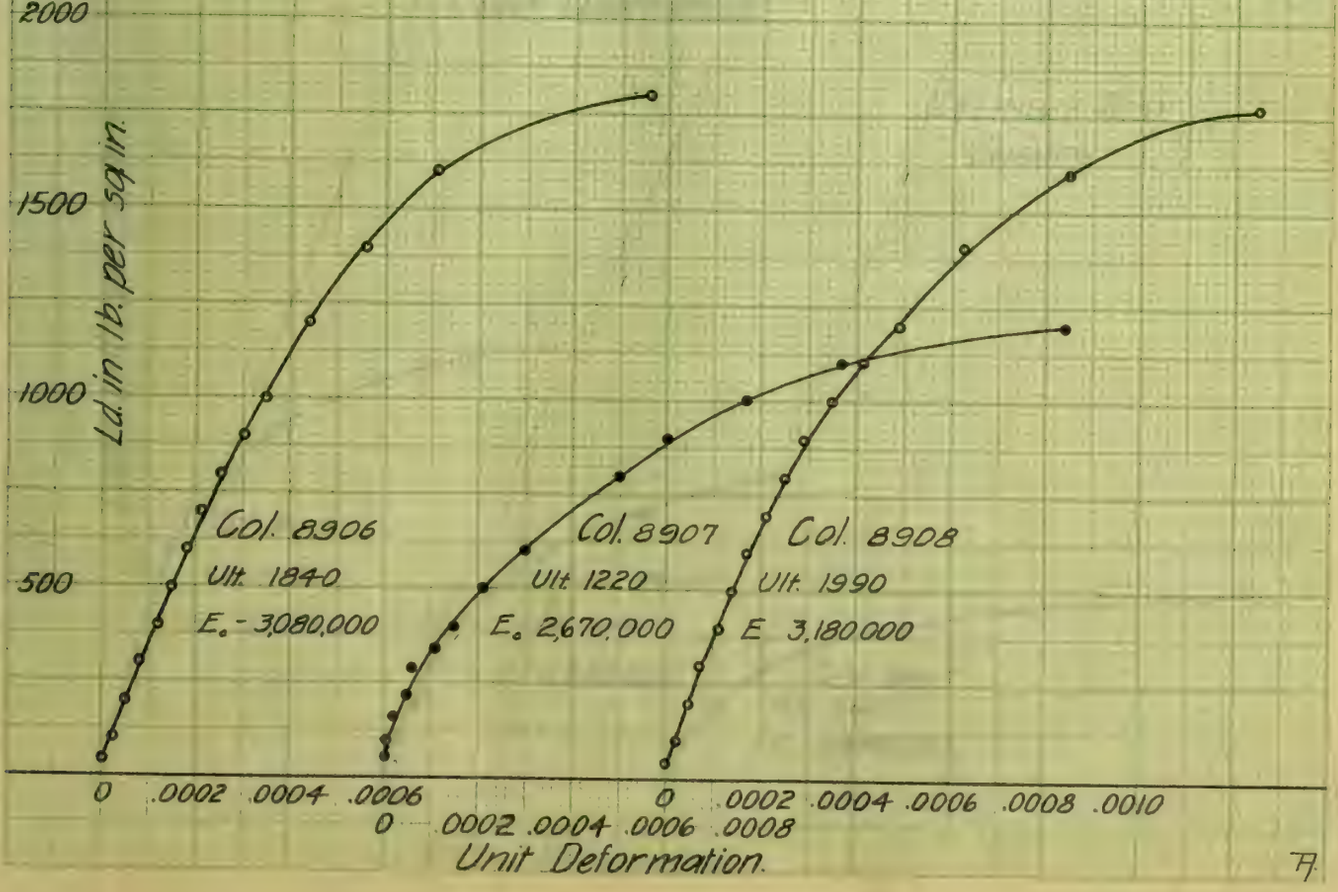
Each curve an average of six tests.



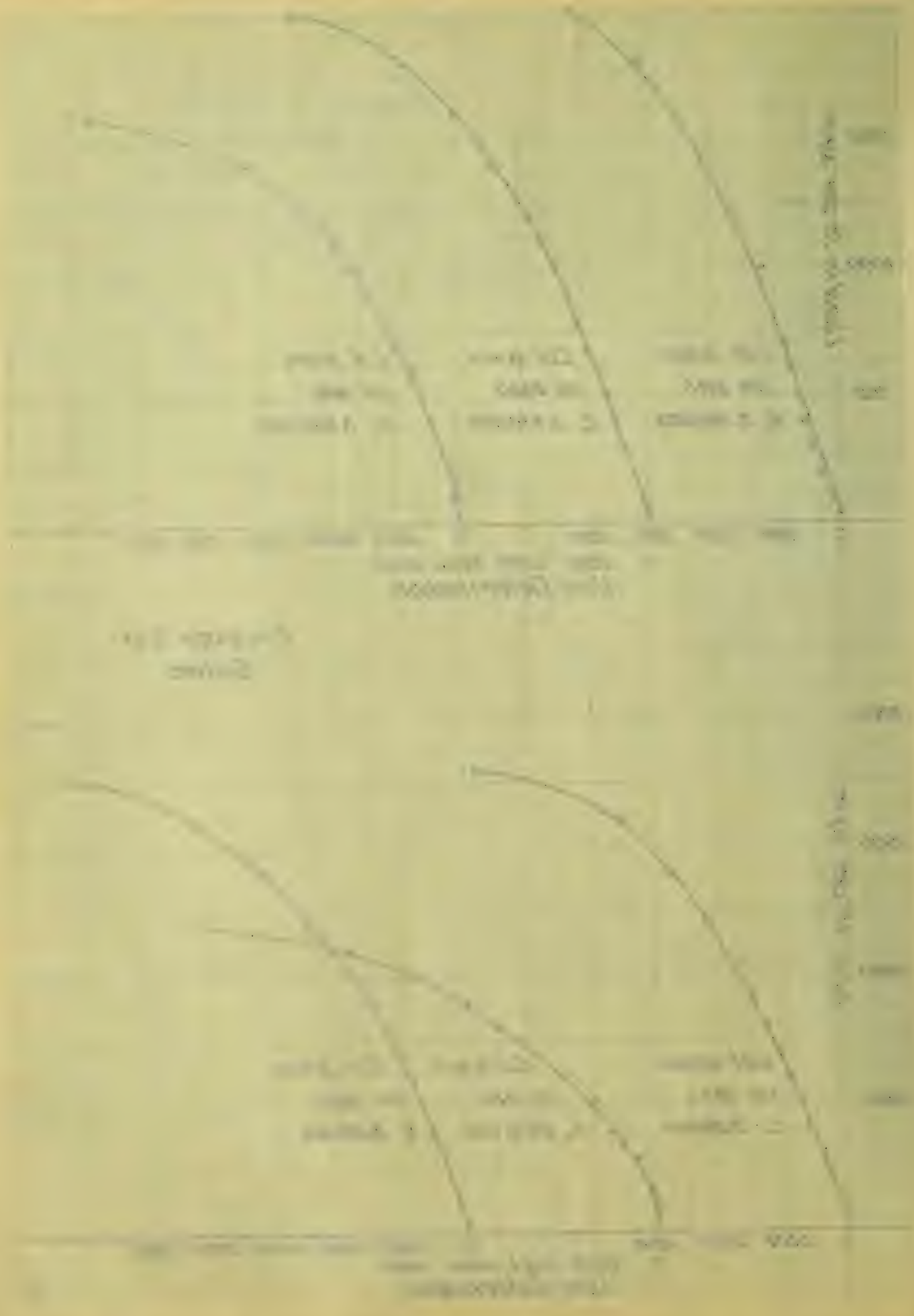


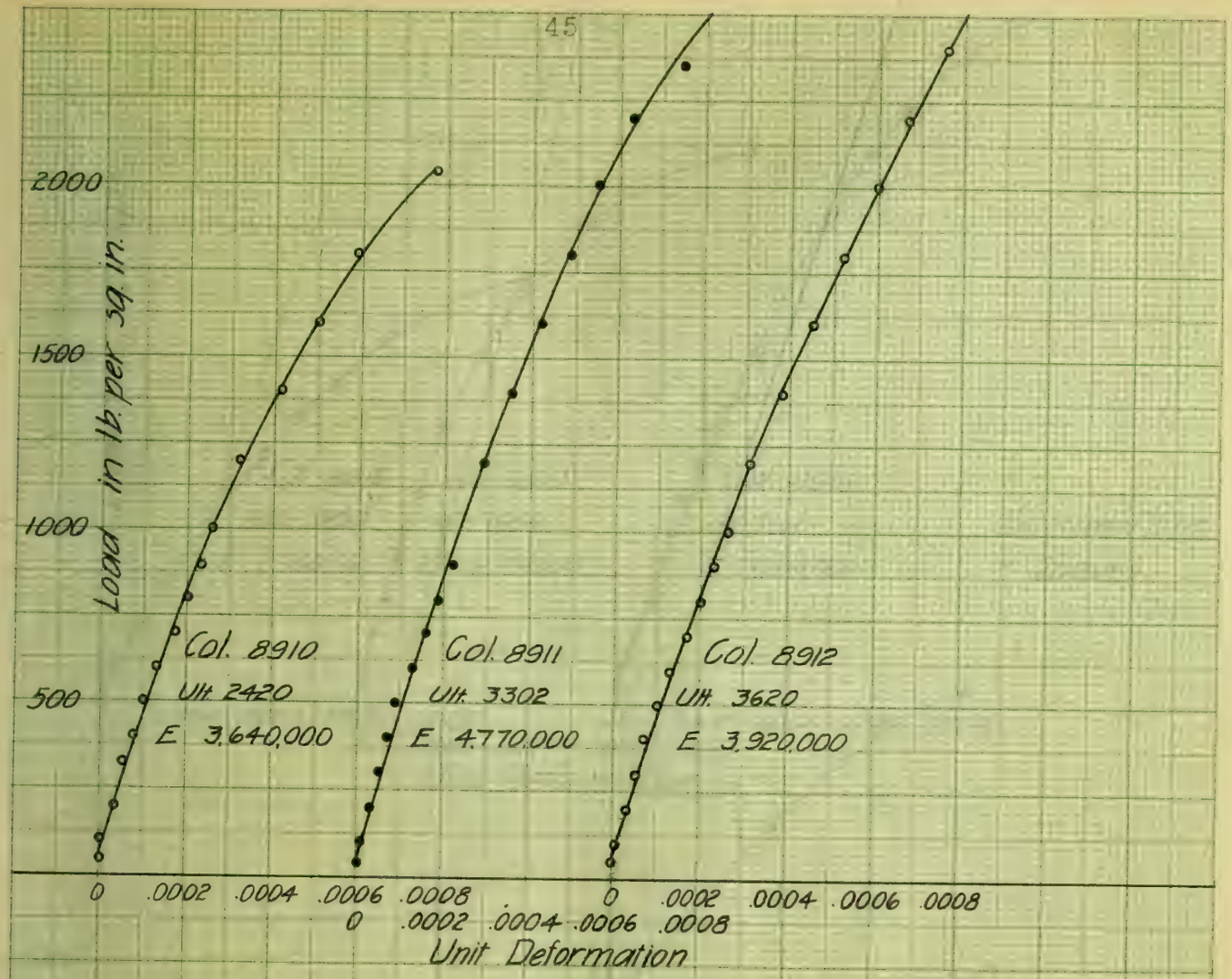


CYLINDER TEST CURVES.

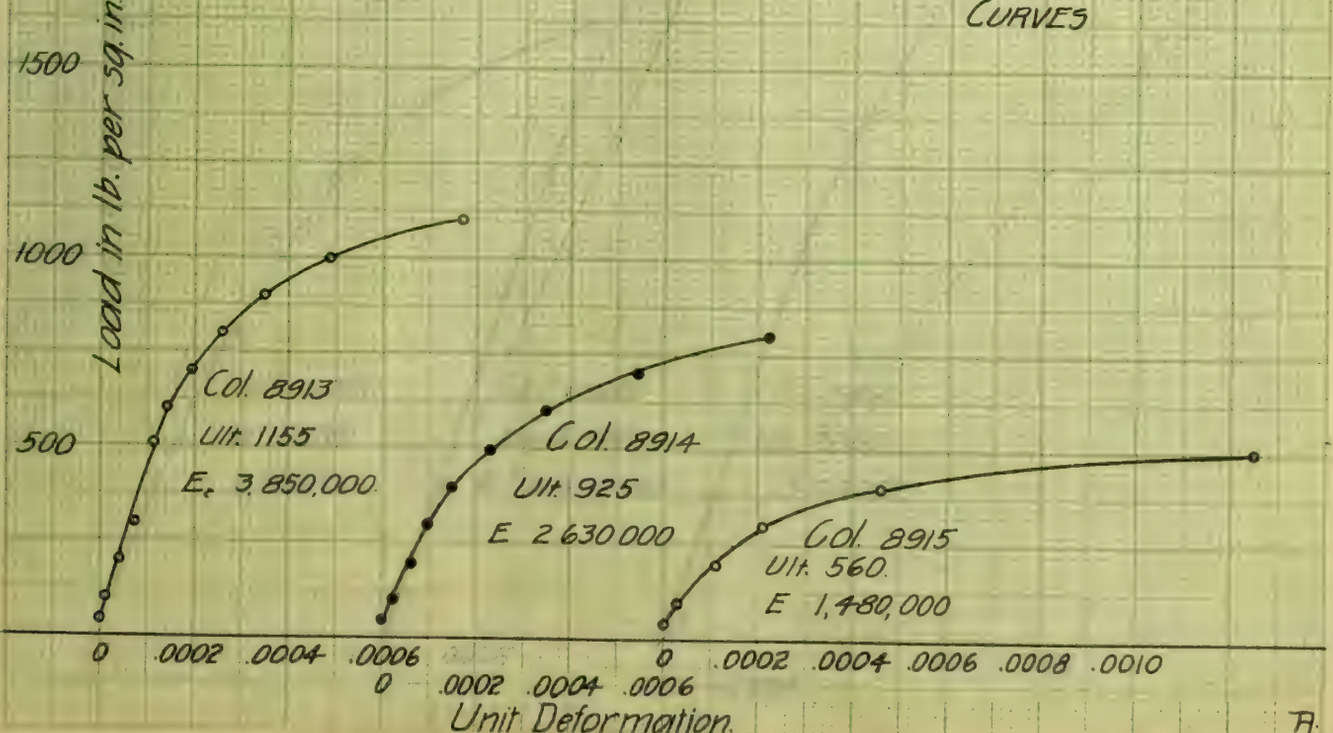


A.



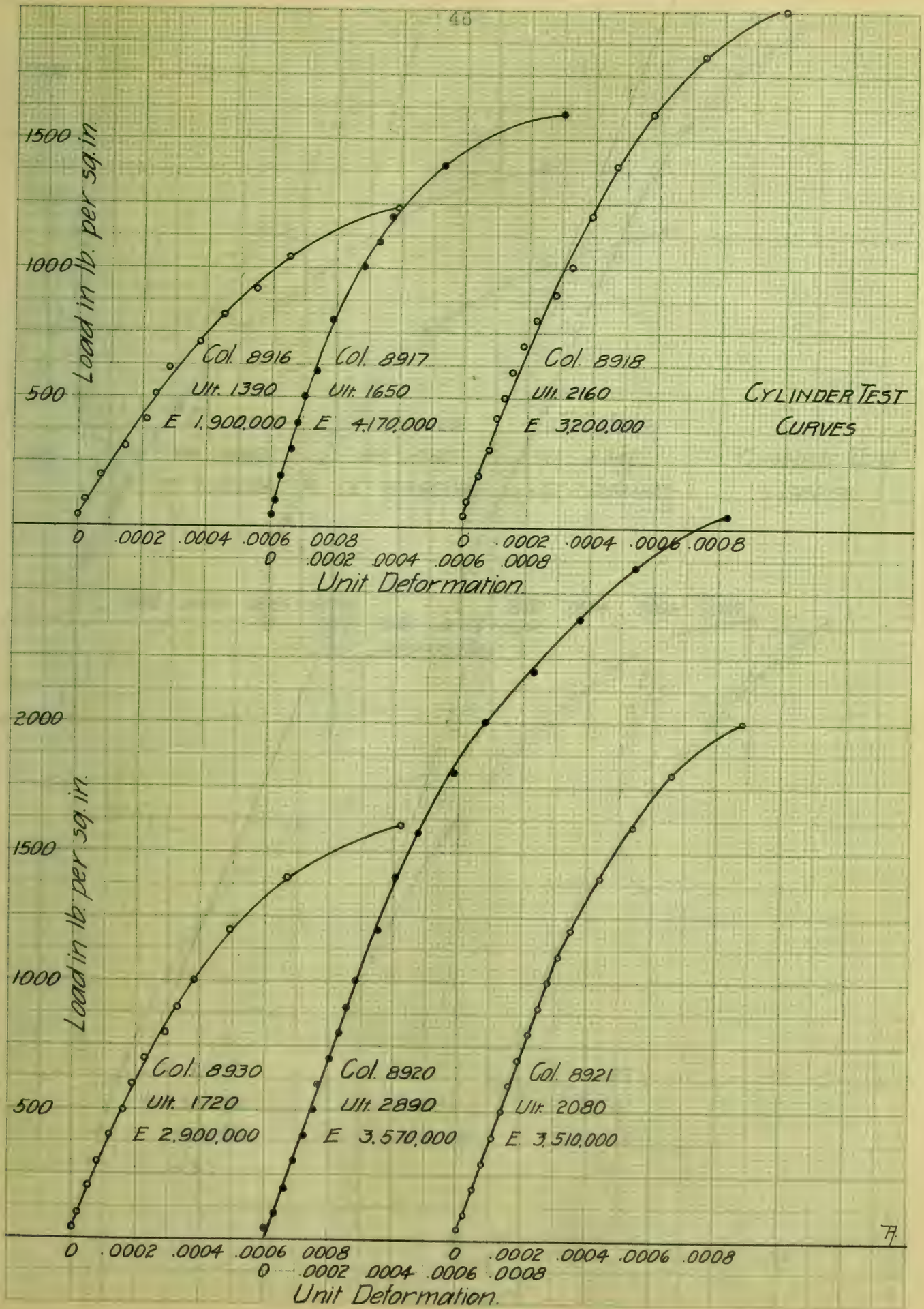


CYLINDER TEST CURVES



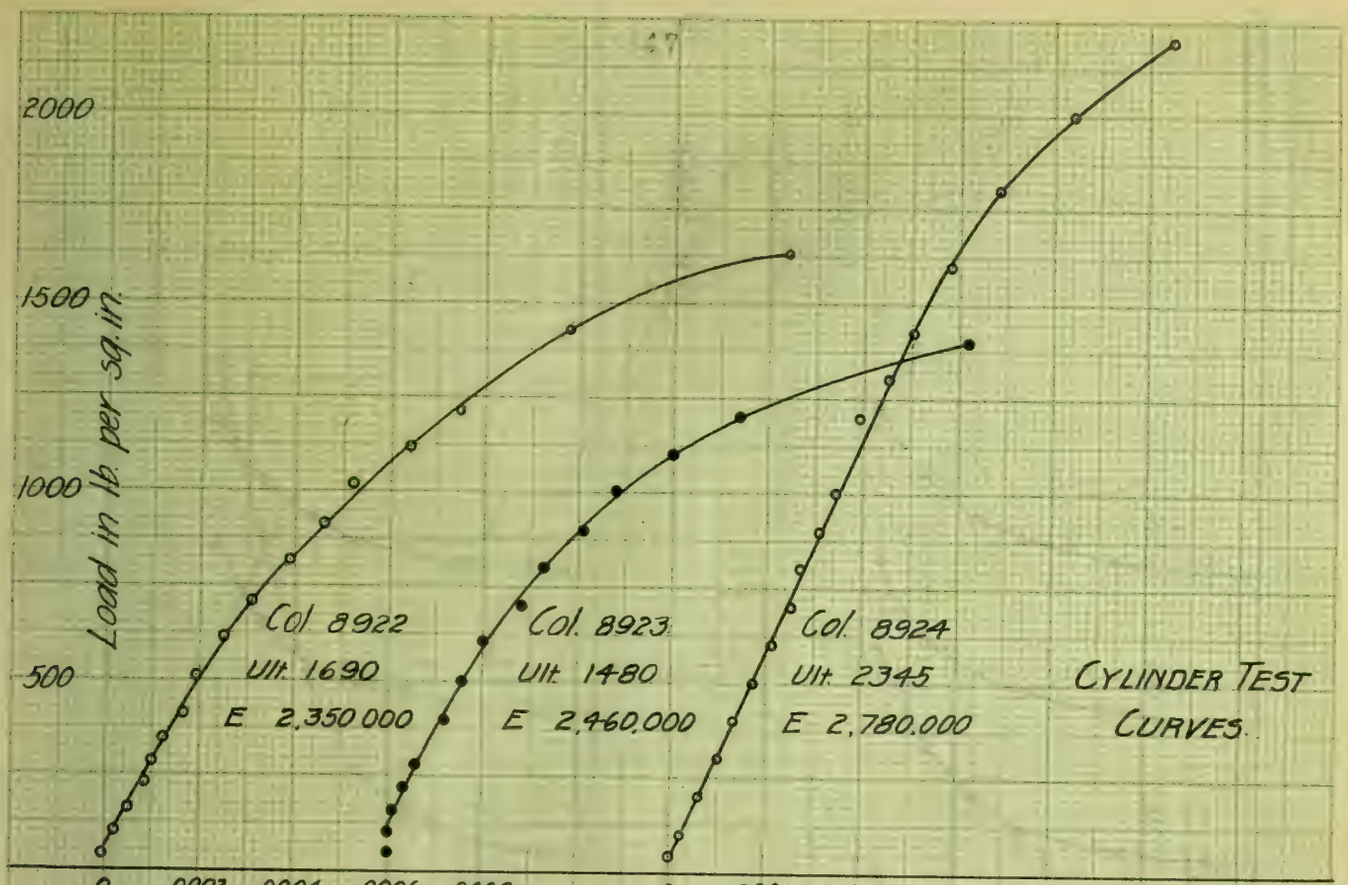
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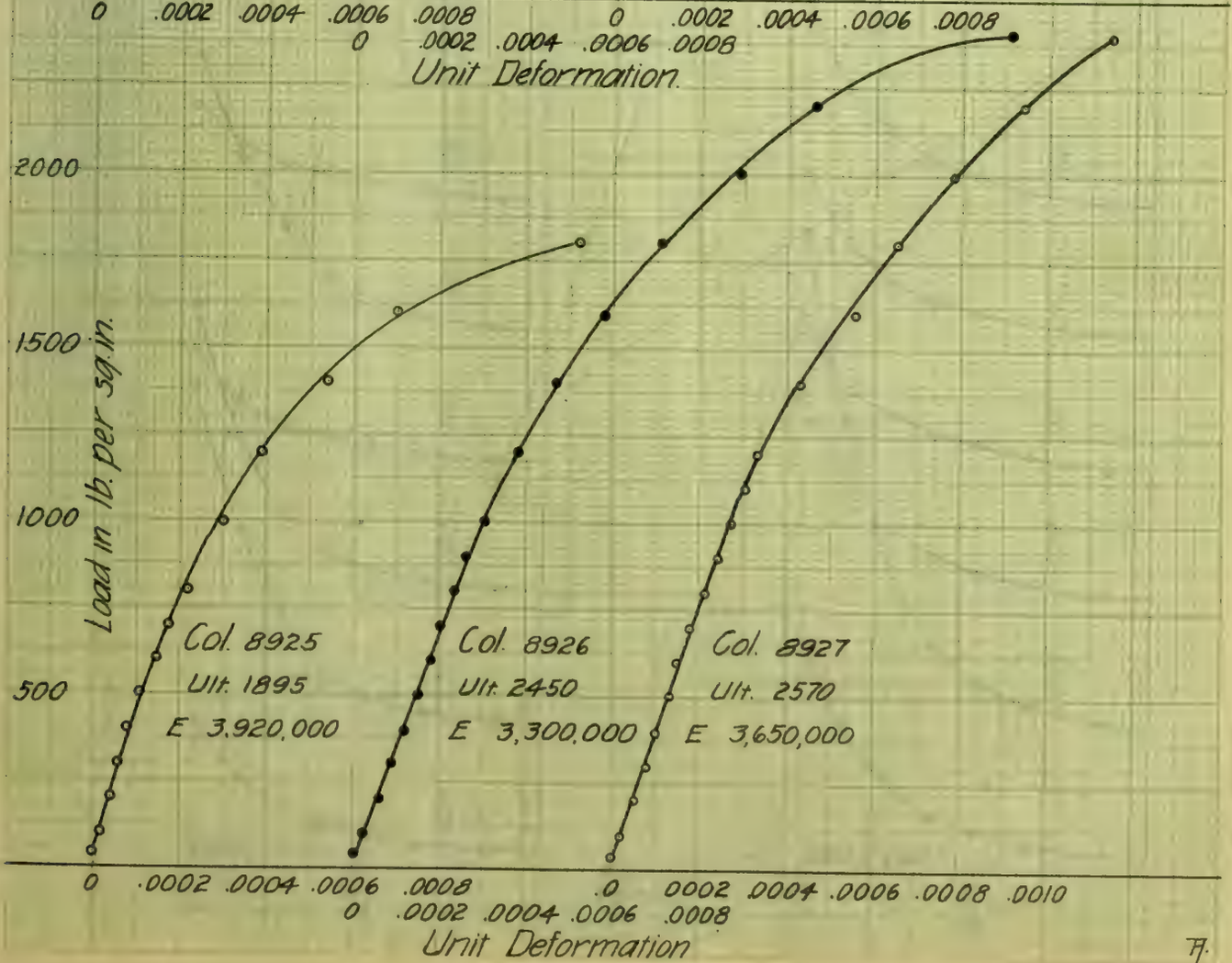

1500
1000
500
Load in lb. per sq. in.
Col. 8916
Ult. 1390
E 1,900,000
Col. 8917
Ult. 1650
E 4,170,000
Col. 8918
Ult. 2160
E 3,200,000
CYLINDER TEST CURVES
0 .0002 .0004 .0006 .0008
0 .0002 .0004 .0006 .0008
0 .0002 .0004 .0006 .0008
Unit Deformation.

2000
1500
1000
500
Load in lb. per sq. in.
Col. 8930
Ult. 1720
E 2,900,000
Col. 8920
Ult. 2890
E 3,570,000
Col. 8921
Ult. 2080
E 3,510,000
A.
0 .0002 .0004 .0006 .0008
0 .0002 .0004 .0006 .0008
0 .0002 .0004 .0006 .0008
Unit Deformation.



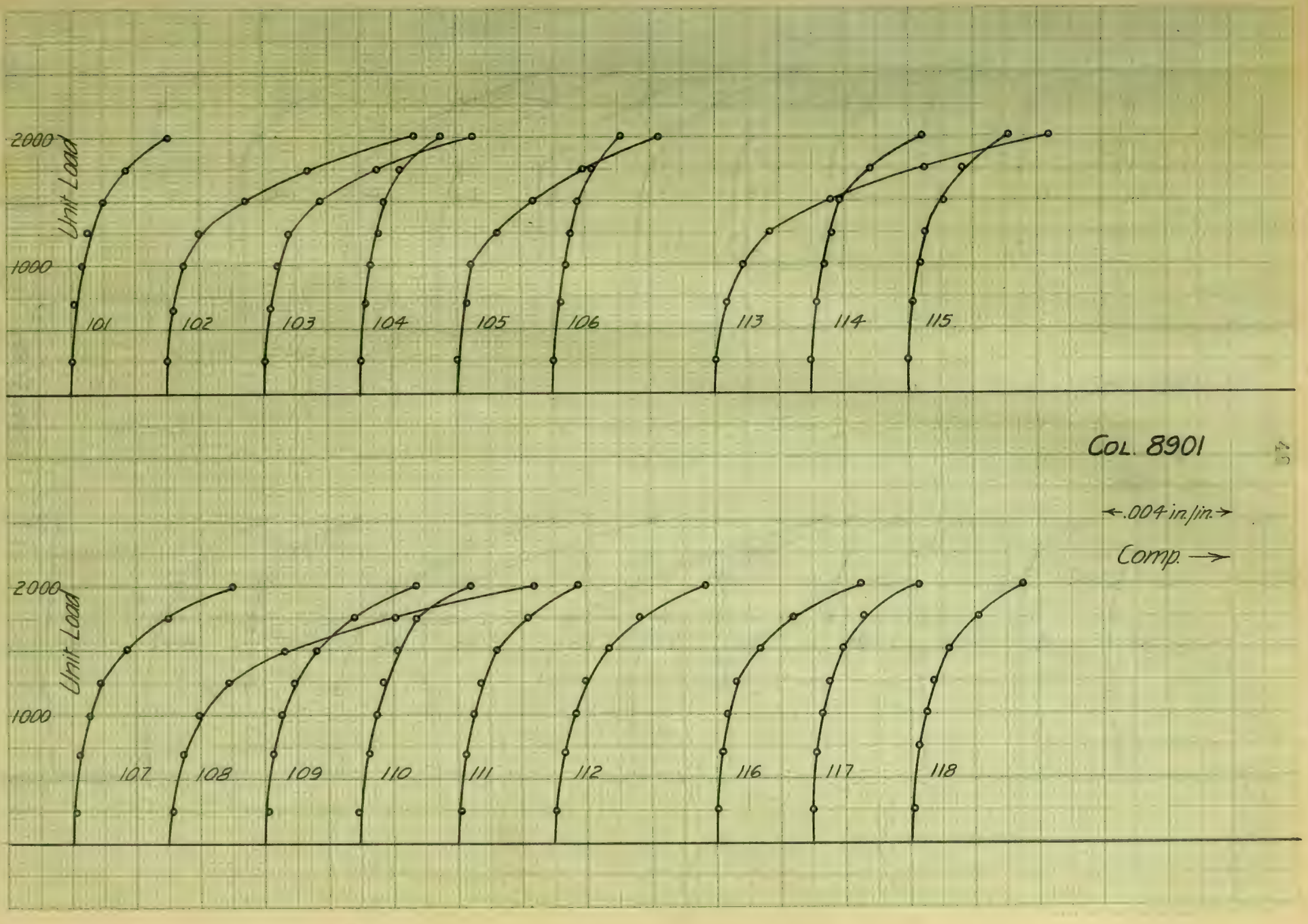


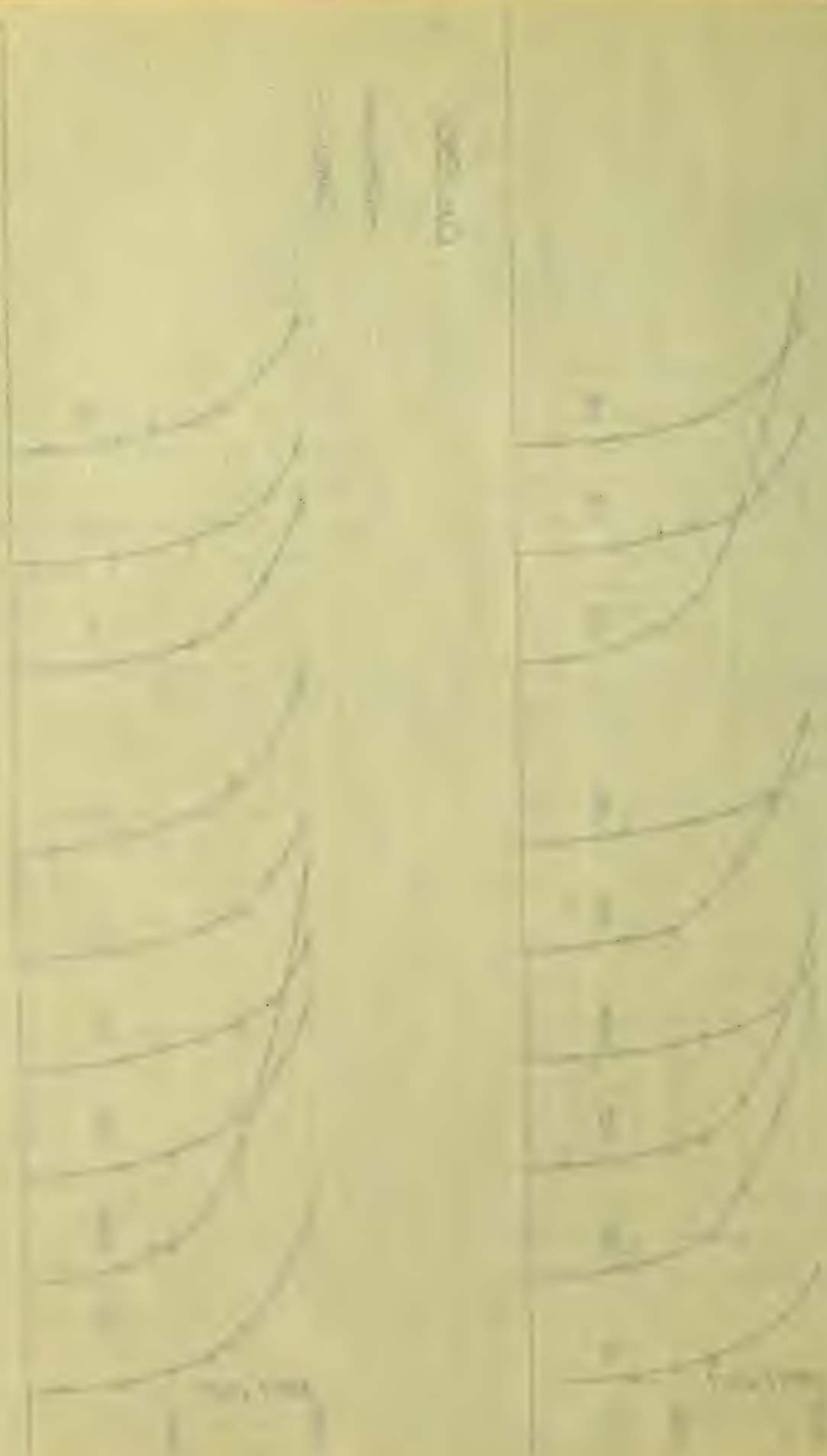
CYLINDER TEST CURVES.

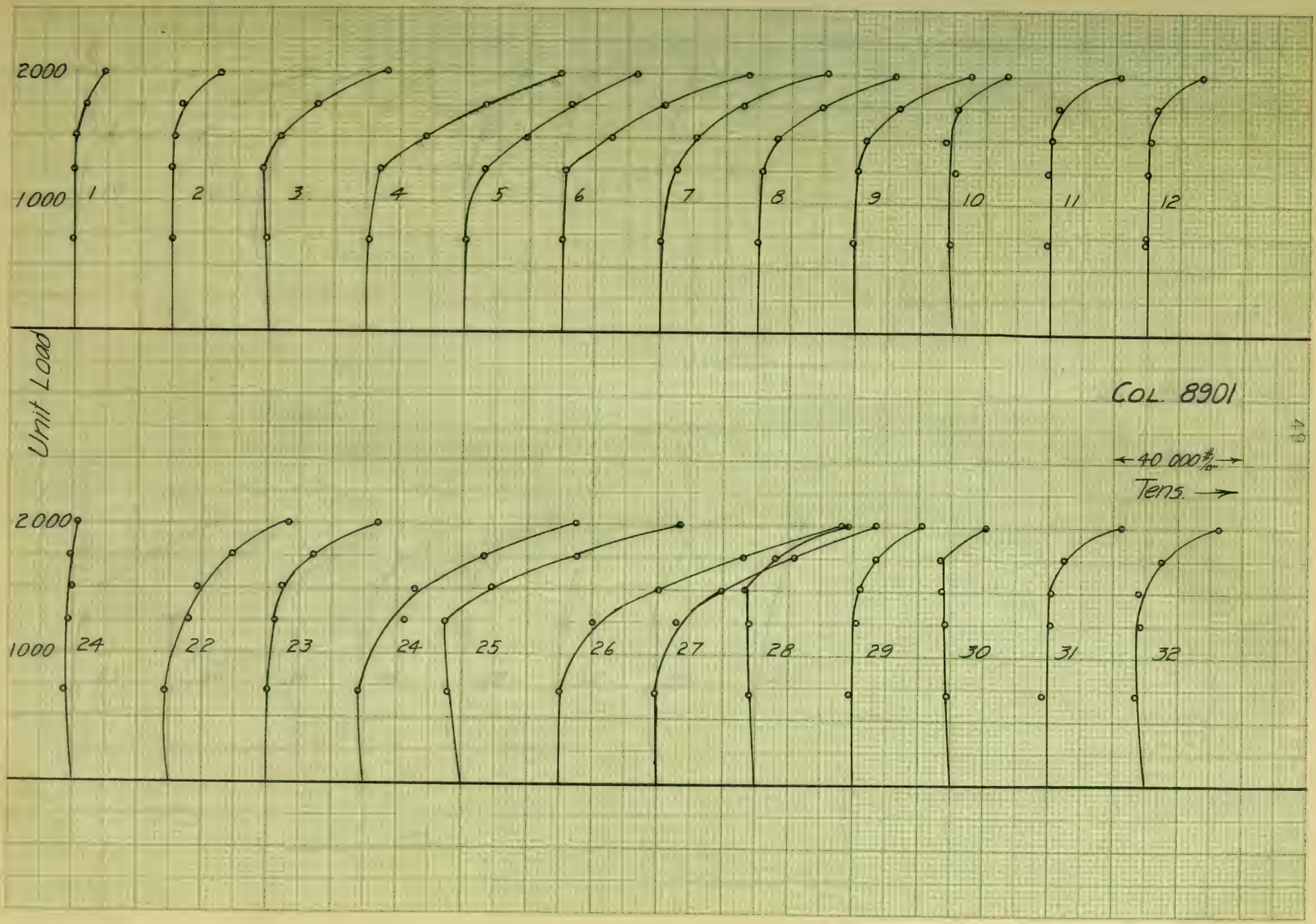


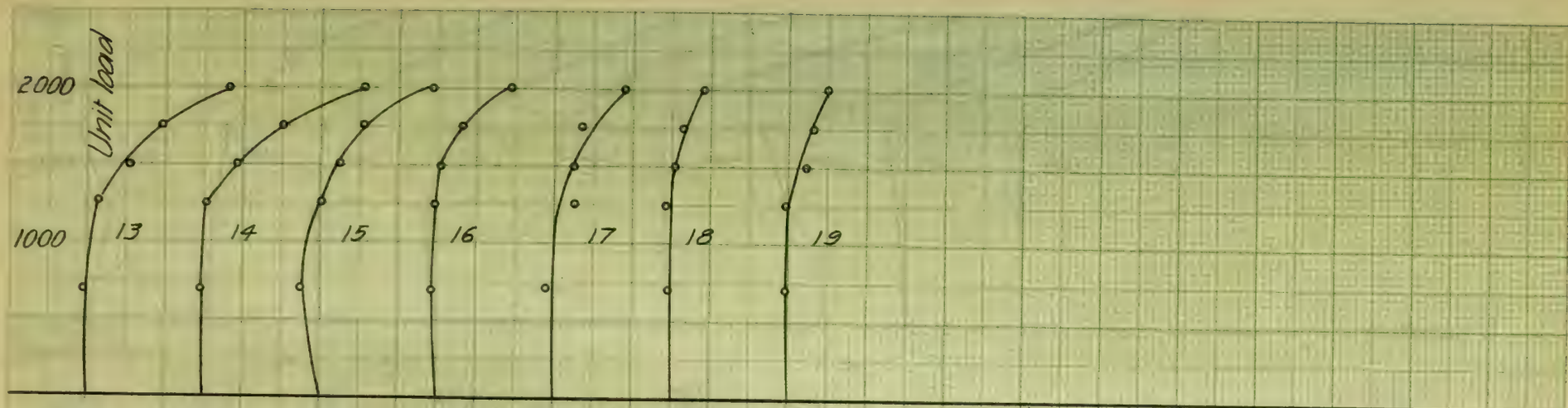
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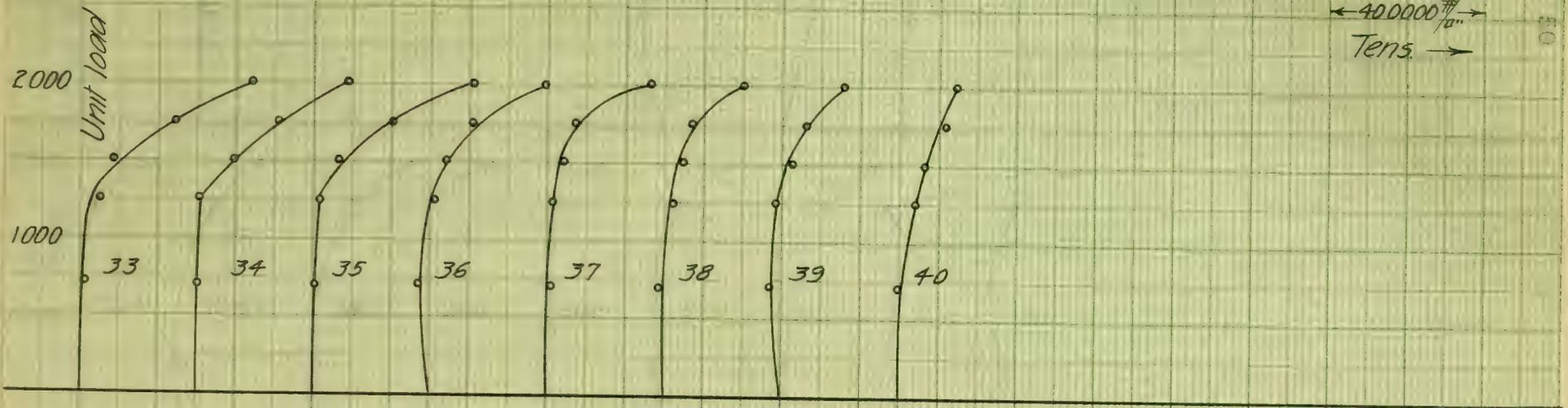



2000
Unit Load
1000
101
102
103
104
105
106
113
114
115
Col. 8901
←.004 in./in.→
Comp. →
2000
Unit Load
1000
107
108
109
110
111
112
116
117
118




2000
1000
1
2
3
4
5
6
7
8
9
10
11
12
Unit Load
COL. 8901
40 000 #/in²
Tens.
2000
1000
24
22
23
24
25
26
27
28
29
30
31
32



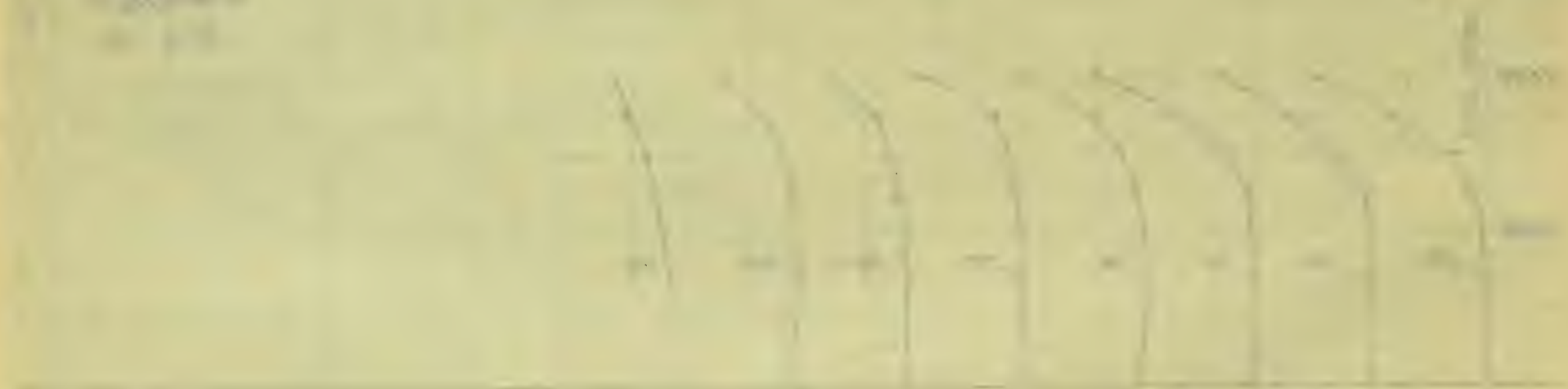


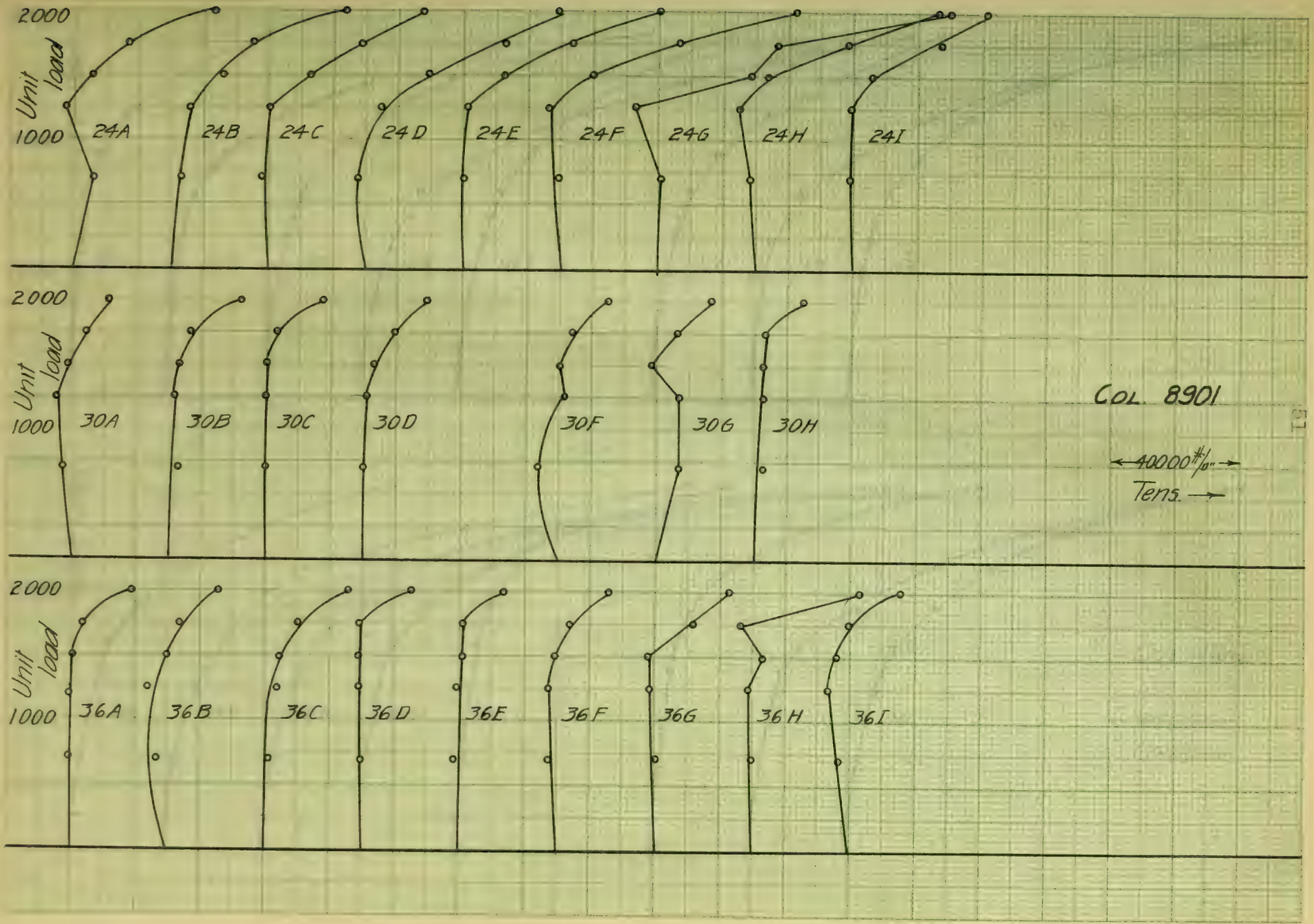
COL 8901

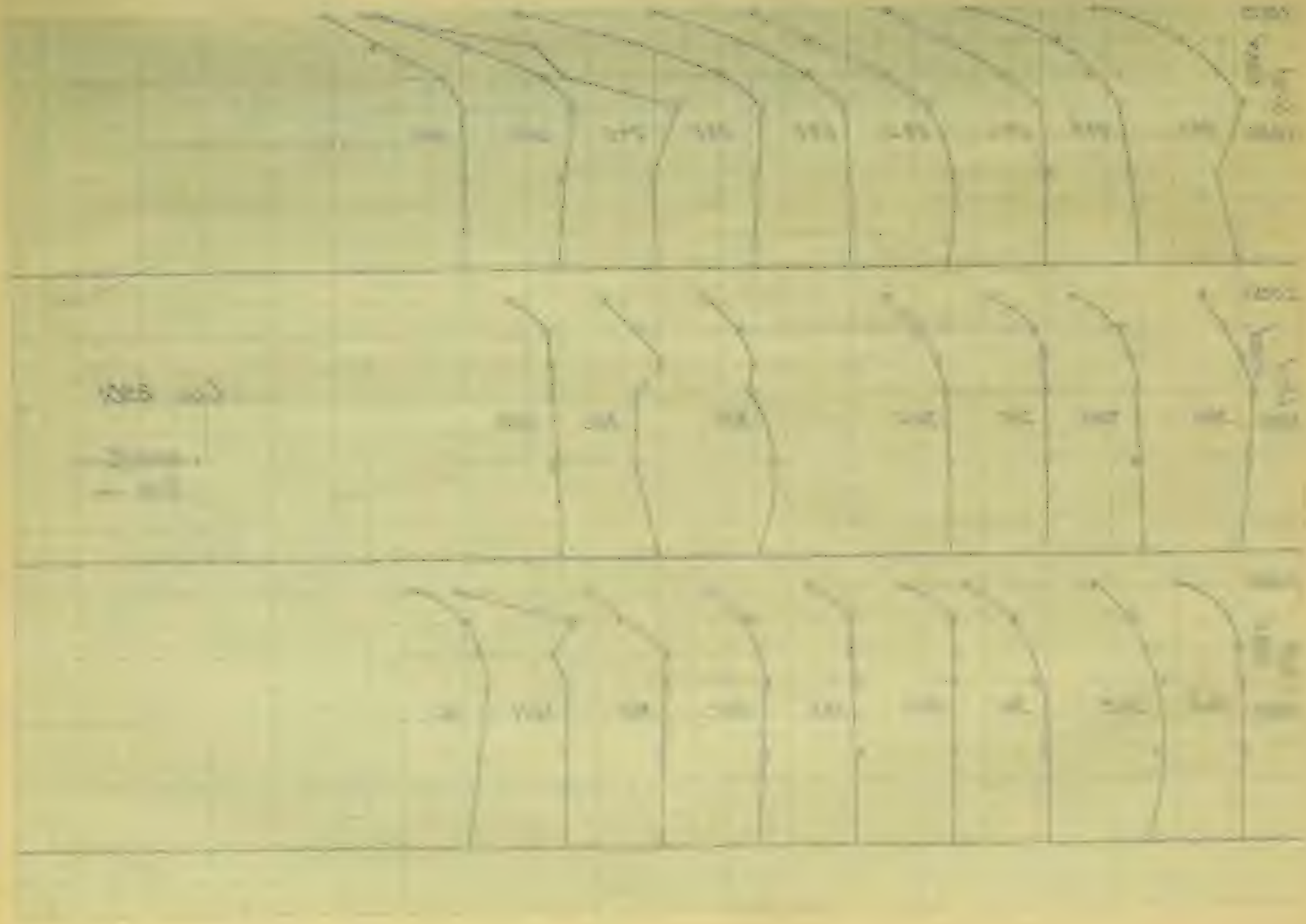
← 400000 #/a" →

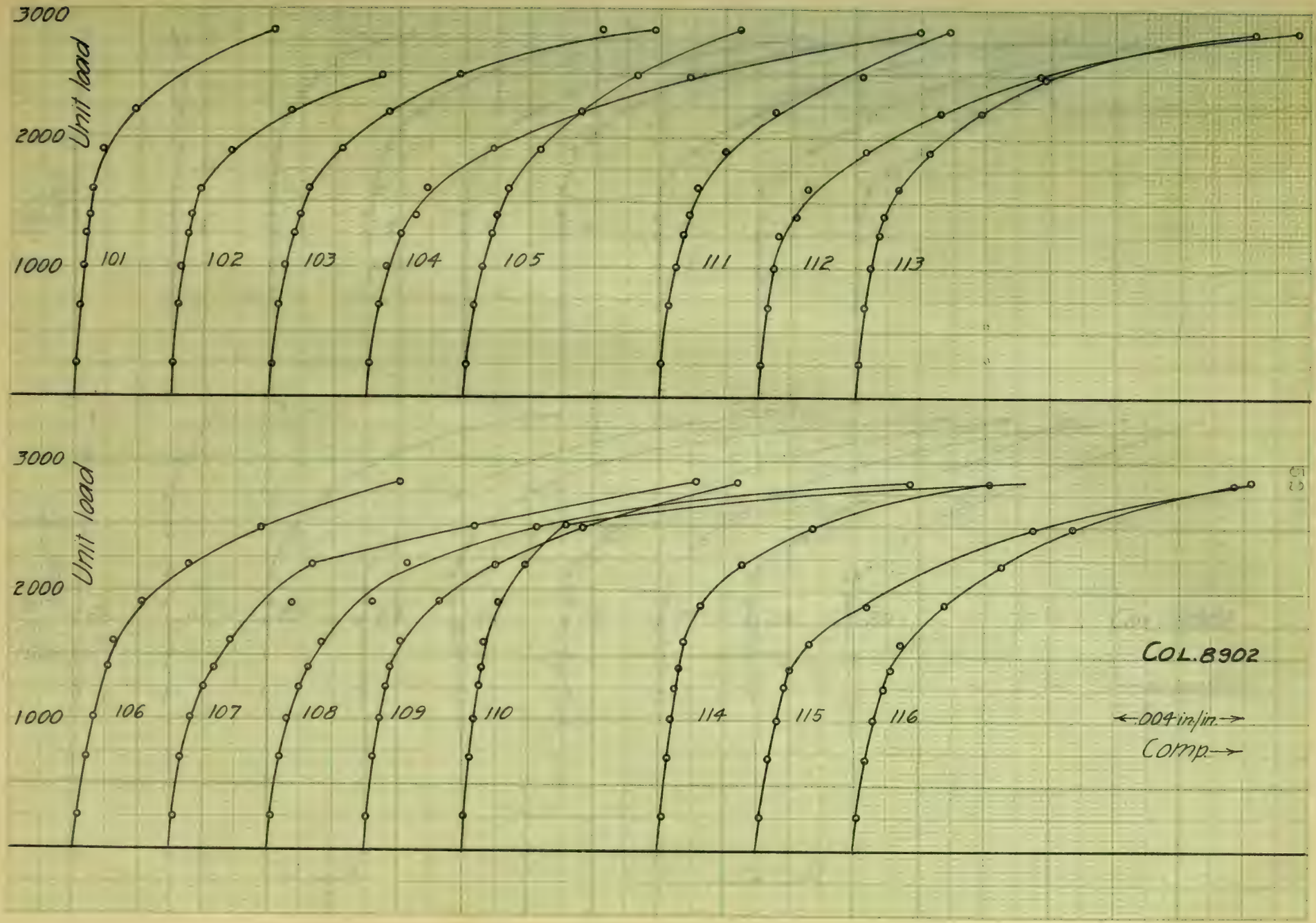
Tens. →



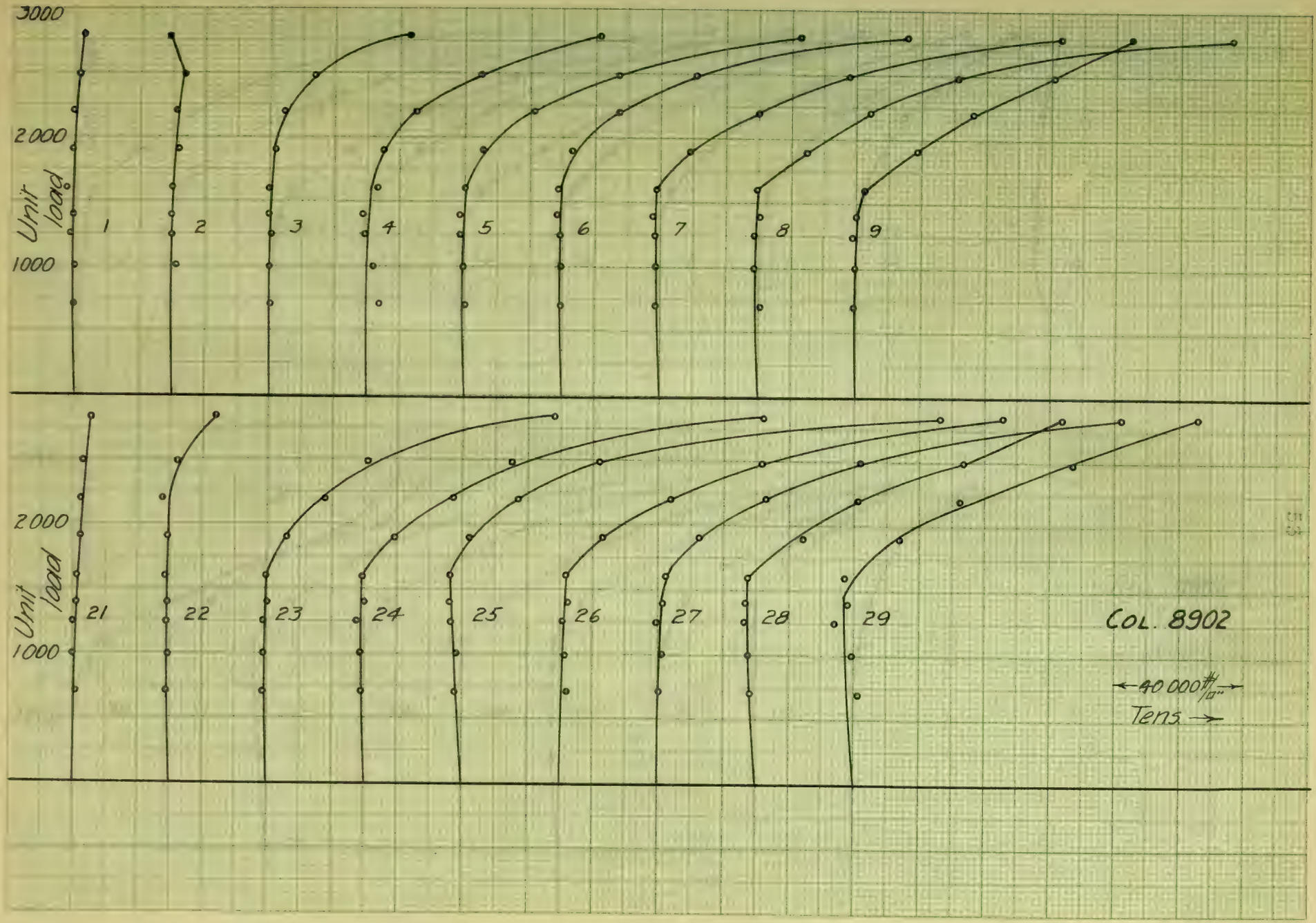


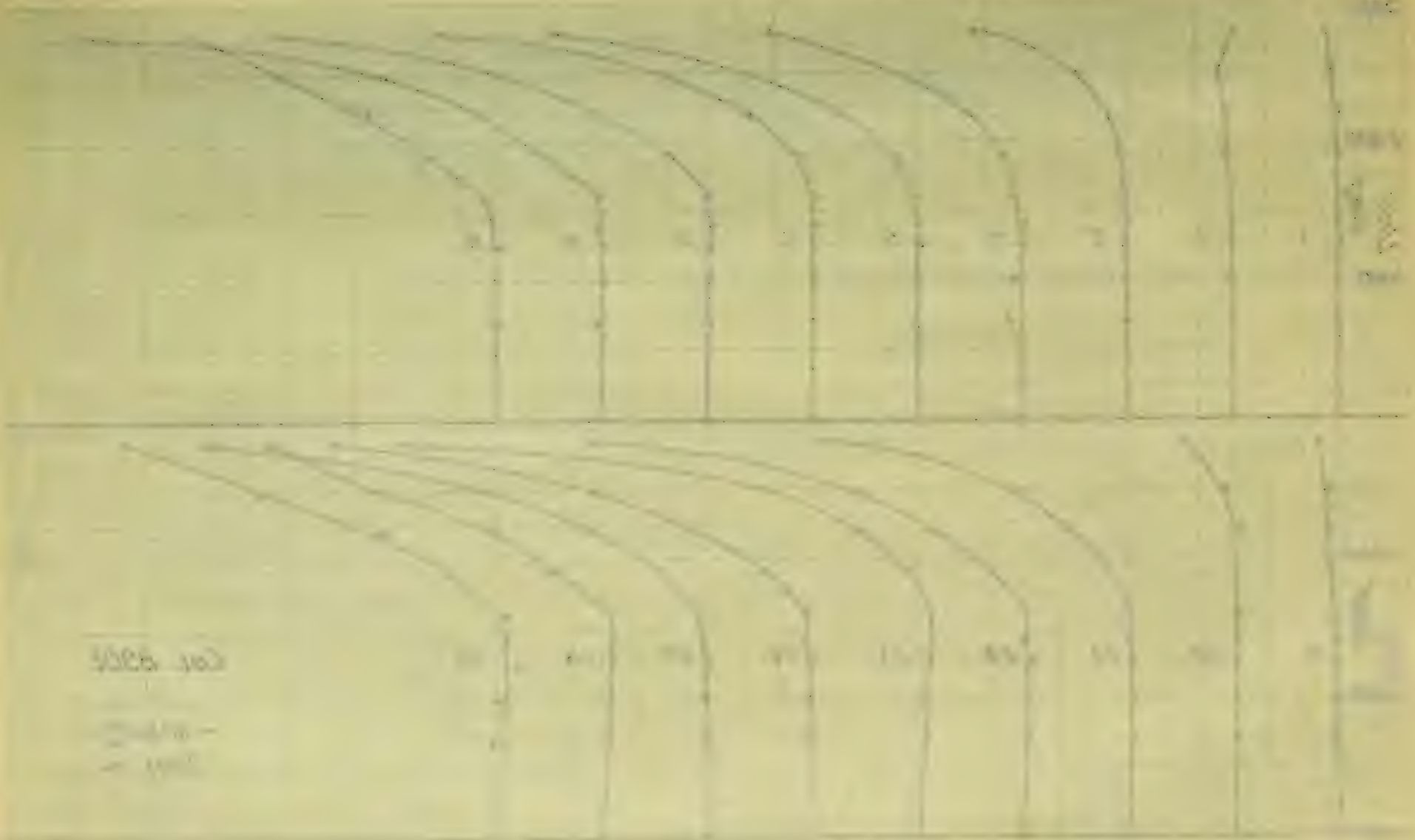

2000
Unit load
1000
24A
24B
24C
24D
24E
24F
24G
24H
24I
2000
Unit load
1000
30A
30B
30C
30D
30F
30G
30H
2000
Unit load
1000
36A
36B
36C
36D
36E
36F
36G
36H
36I
Col. 8901
40000 #/in
Tens.

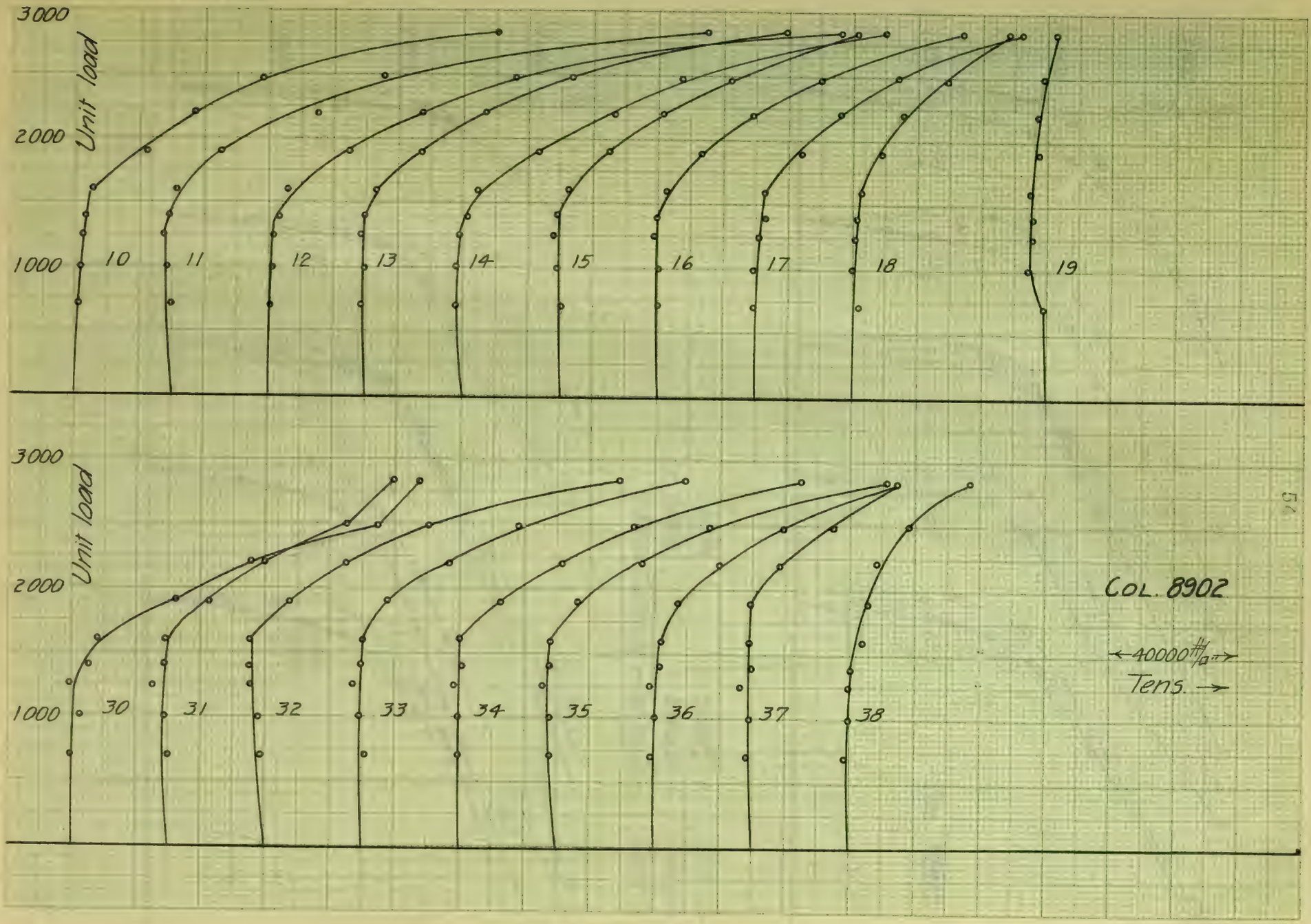



3000
Unit load
2000
1000
101
102
103
104
105
111
112
113
3000
Unit load
2000
1000
106
107
108
109
110
114
115
116
COL. 8902
←.004 in/in.→
Comp.→



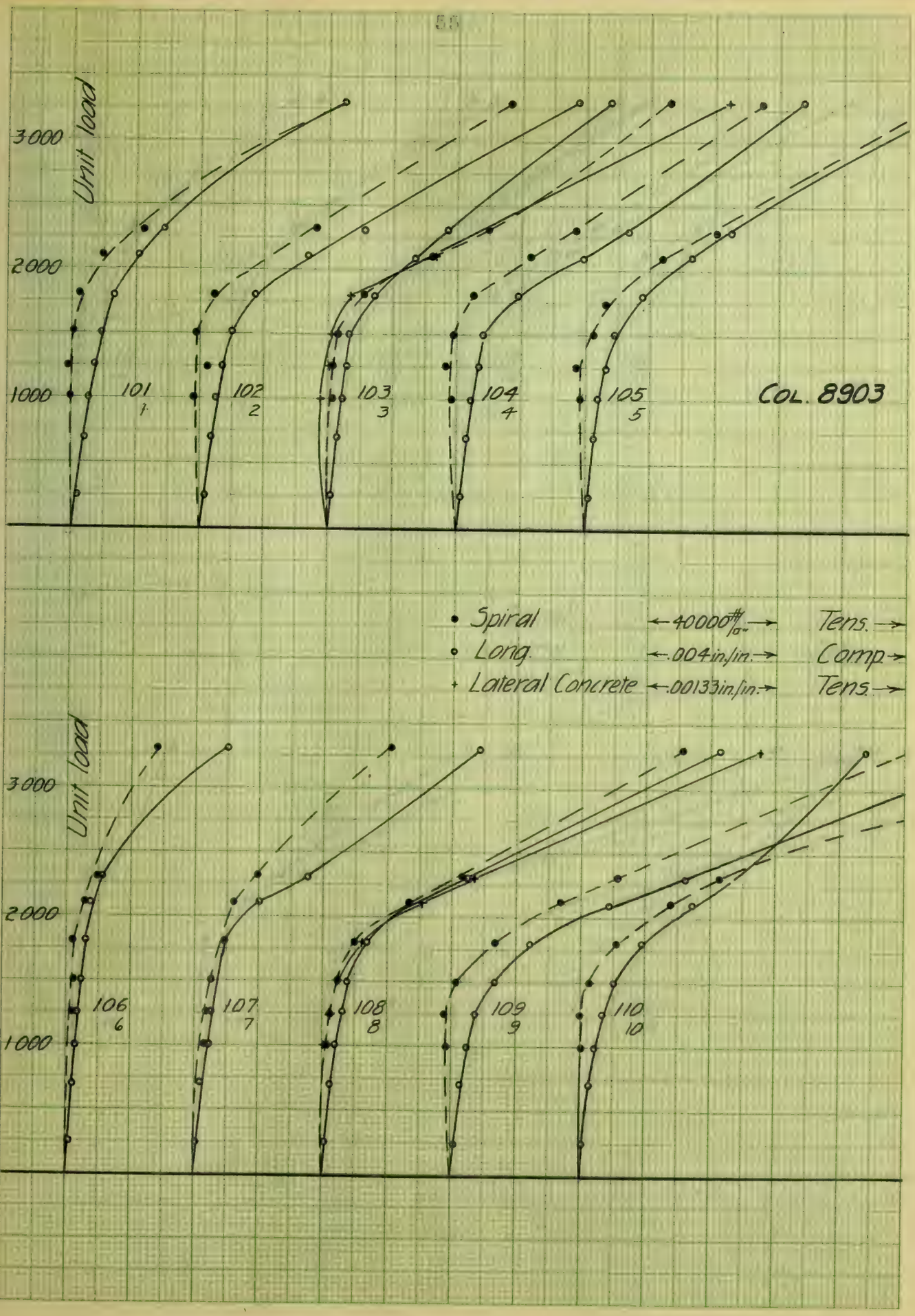

3000
2000
Unit load
1000
1
2
3
4
5
6
7
8
9
2000
Unit load
1000
21
22
23
24
25
26
27
28
29
COL. 8902
40 000#/in
Tens




3000
2000
1000
Unit load
10
11
12
13
14
15
16
17
18
19
3000
2000
1000
Unit load
30
31
32
33
34
35
36
37
38
COL. 8902
←40000#/□"→
Tens →

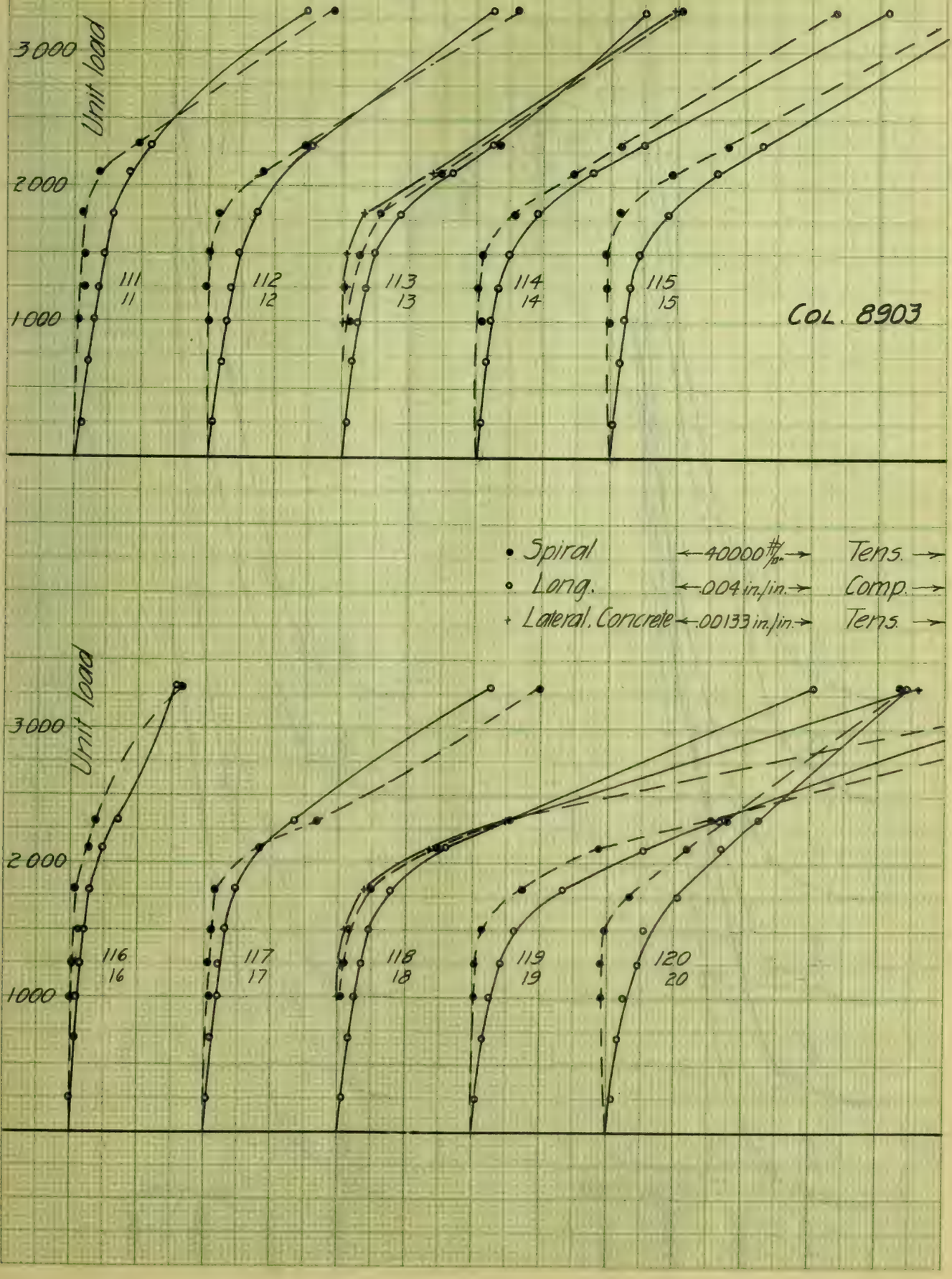





Unit load
3000
2000
1000
101
1
102
2
103
3
104
4
105
5
COL. 8903
• Spiral ←40000#/sq.in.→ Tens. →
• Long. ←.004 in./in.→ Comp →
+ Lateral Concrete ←.00133 in./in.→ Tens. →
Unit load
3000
2000
1000
106
6
107
7
108
8
109
9
110
10

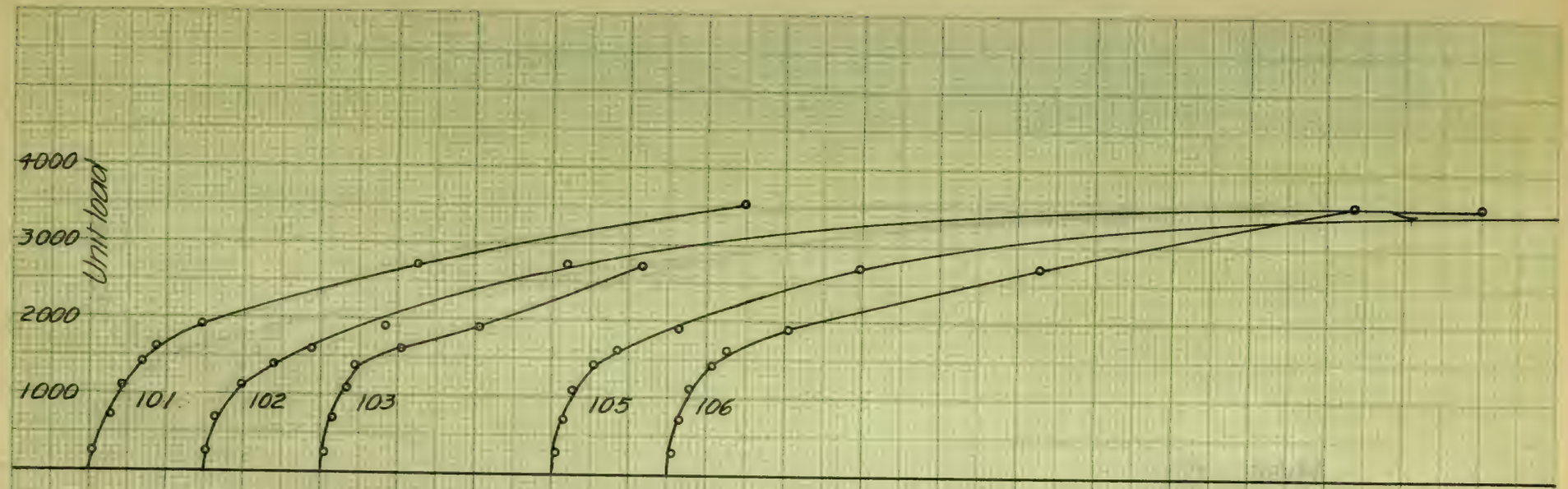





3000
Unit load
2000
1000
111
11
112
12
113
13
114
14
115
15
COL. 8903
• Spiral ←40000 #/in.→ Tens. →
° Long. ←.004 in./in.→ Comp. →
+ Lateral. Concrete ←.00133 in./in.→ Tens. →
3000
Unit load
2000
1000
116
16
117
17
118
18
119
19
120
20

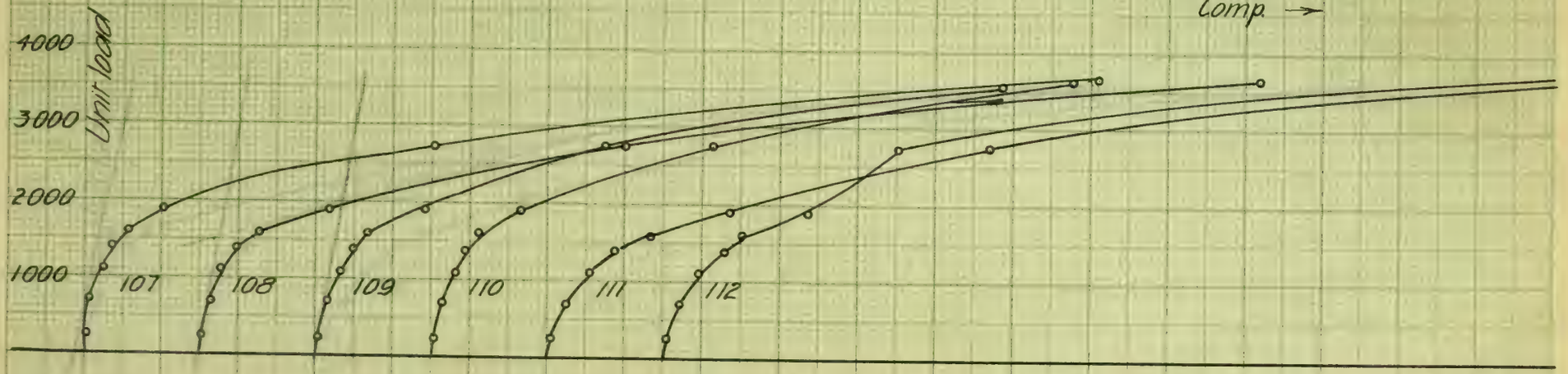






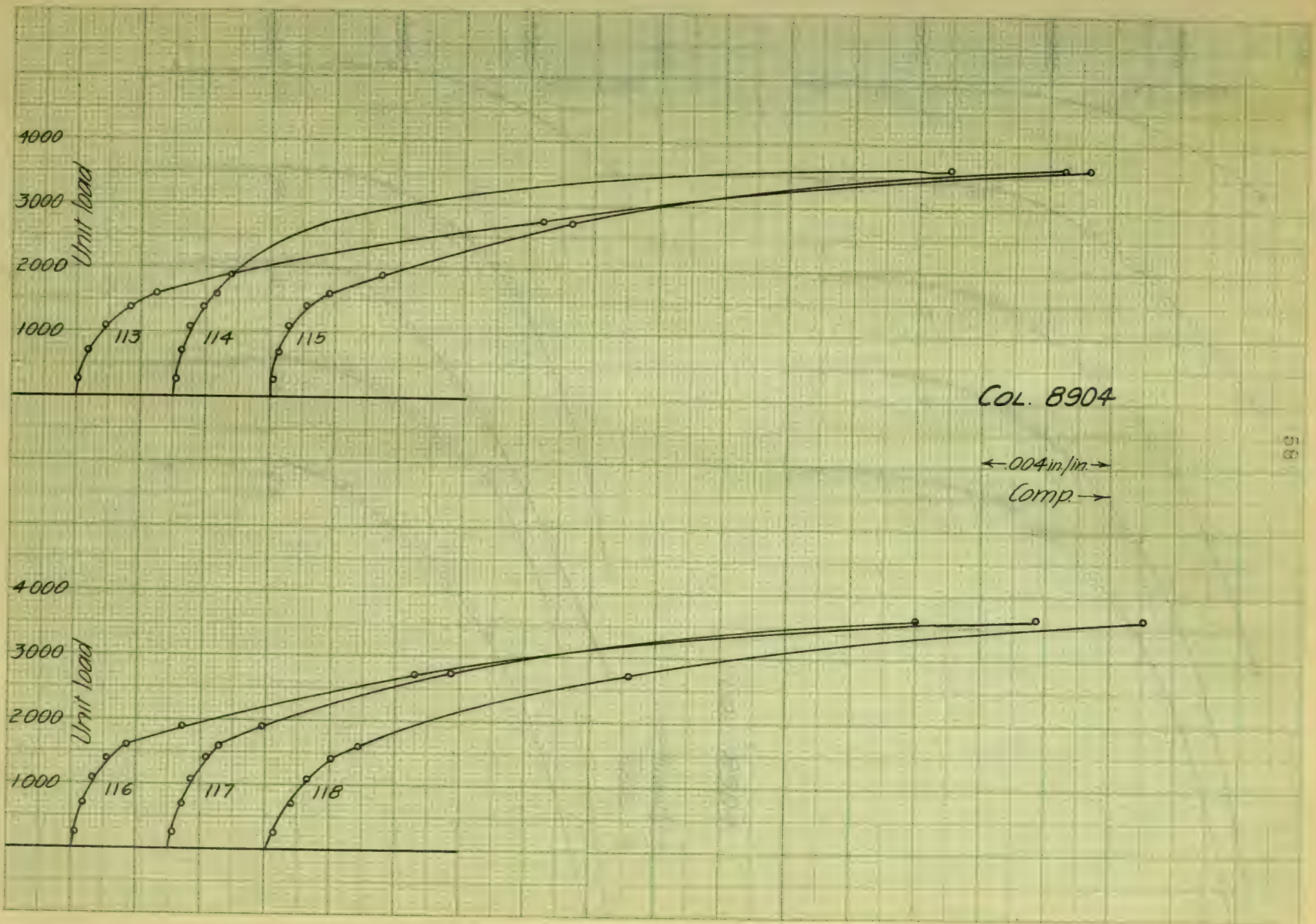
Col. 8904

←.004 in./in.→
Comp. →

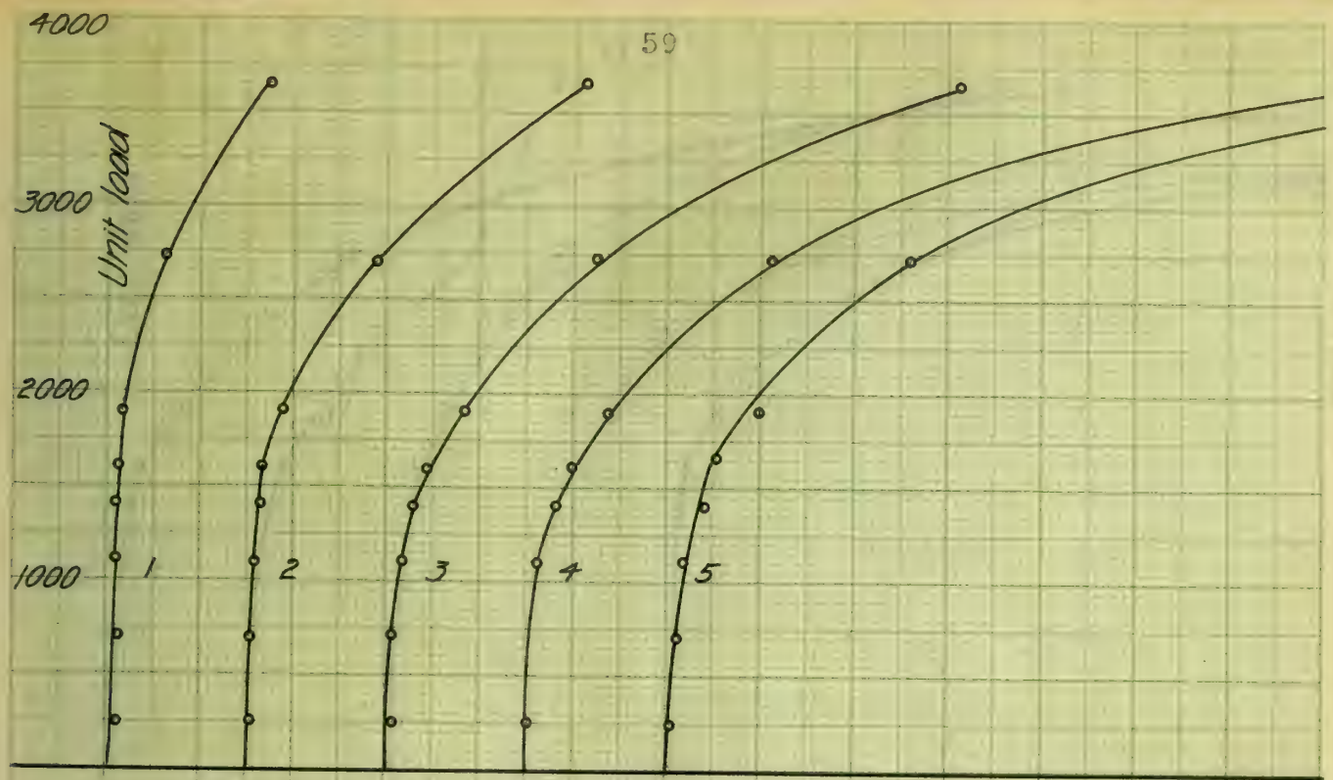


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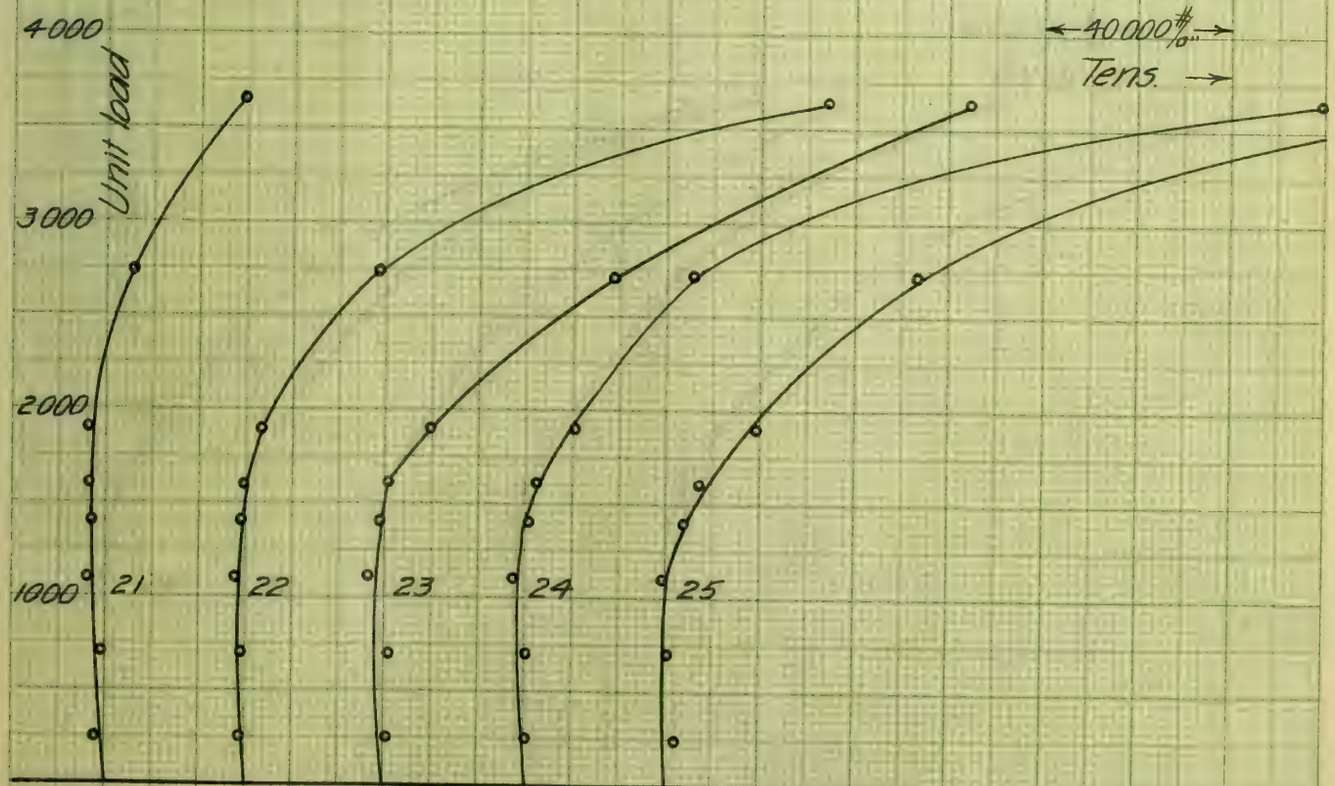



4000
3000
2000
1000
Unit load
113
114
115
COL. 8904
.004 in./in.
Comp.
4000
3000
2000
1000
Unit load
116
117
118



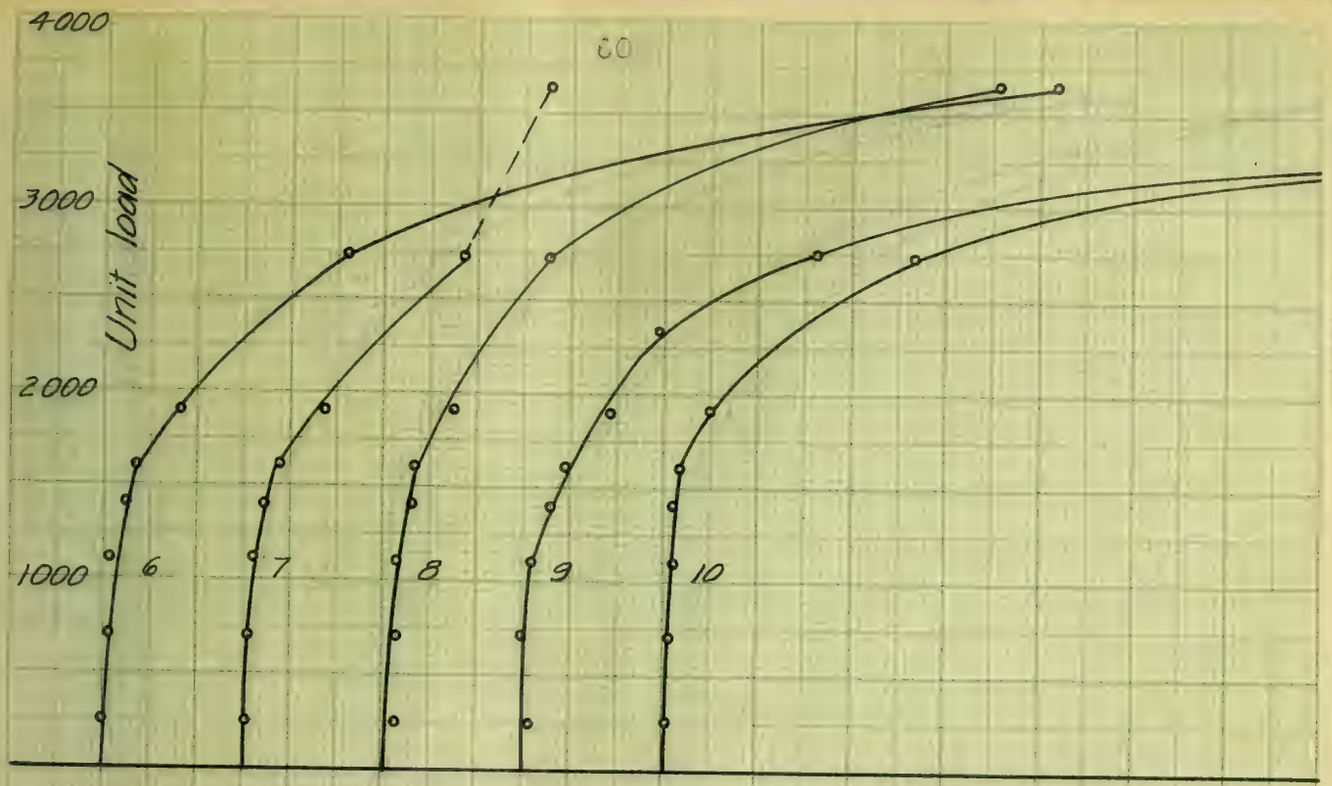

4000
3000
2000
1000
Unit load
1
2
3
4
5

COL. 8904

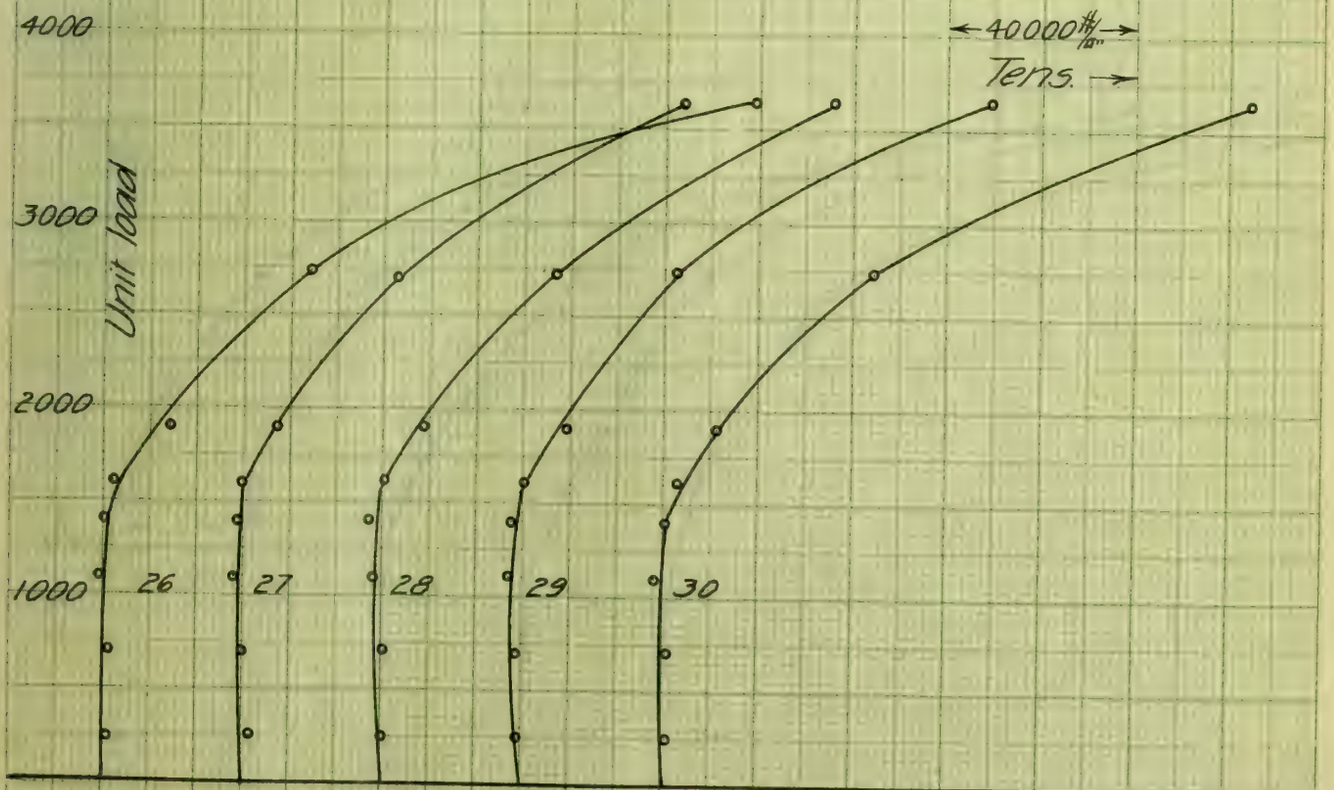

40000 #/□"
Tens.
4000
3000
2000
1000
Unit load
21
22
23
24
25



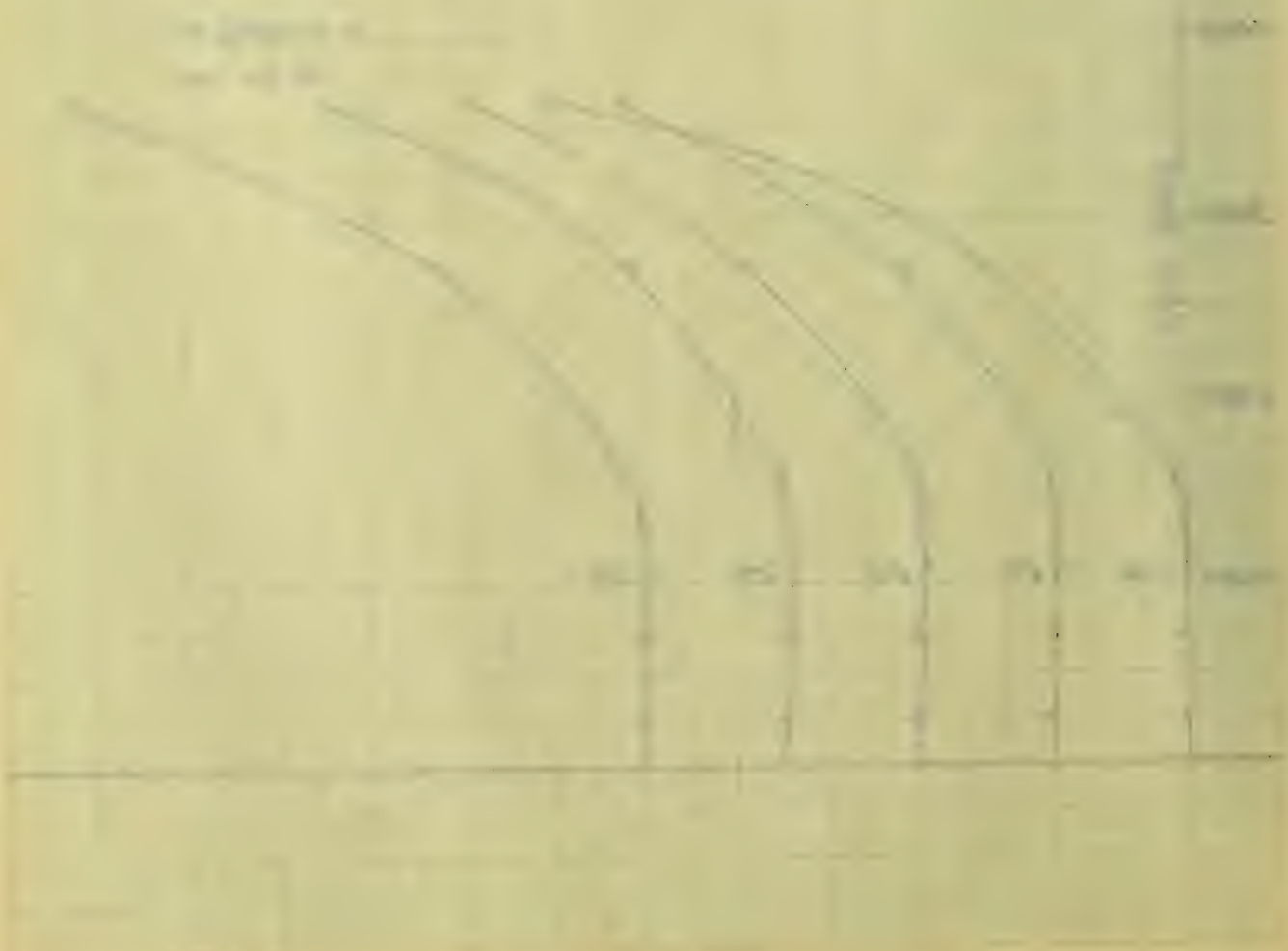


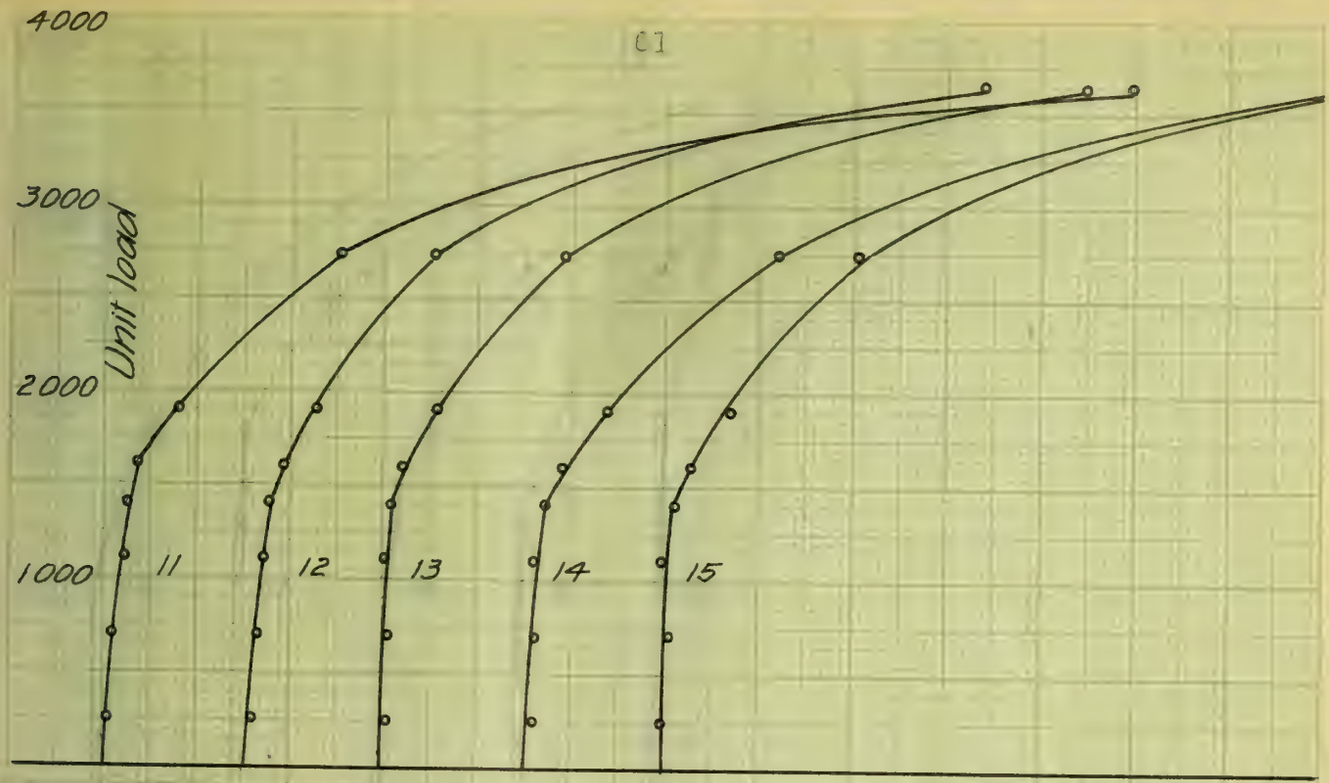

4000
3000
2000
1000
Unit load
6
7
8
9
10

COL. 8904

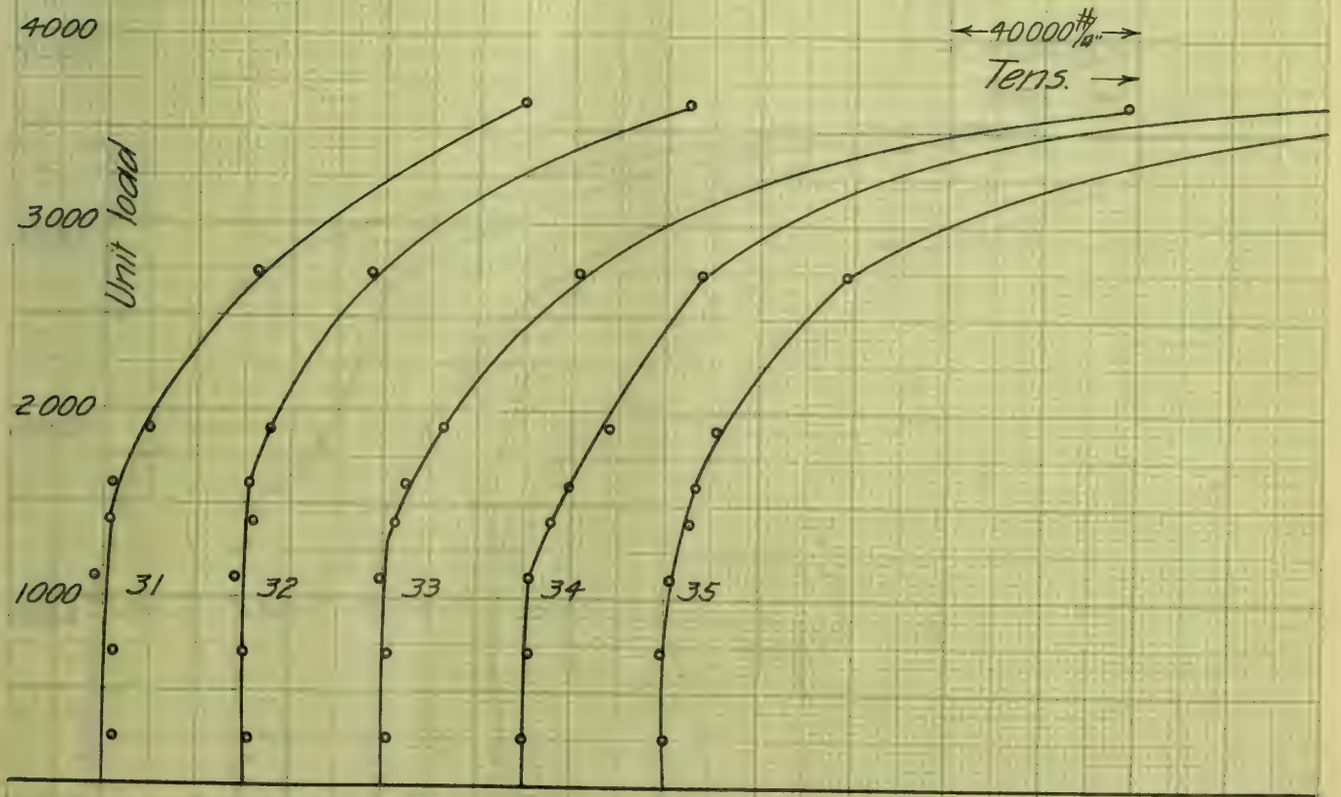

40000 #/in²
Tens.
4000
3000
2000
1000
Unit load
26
27
28
29
30





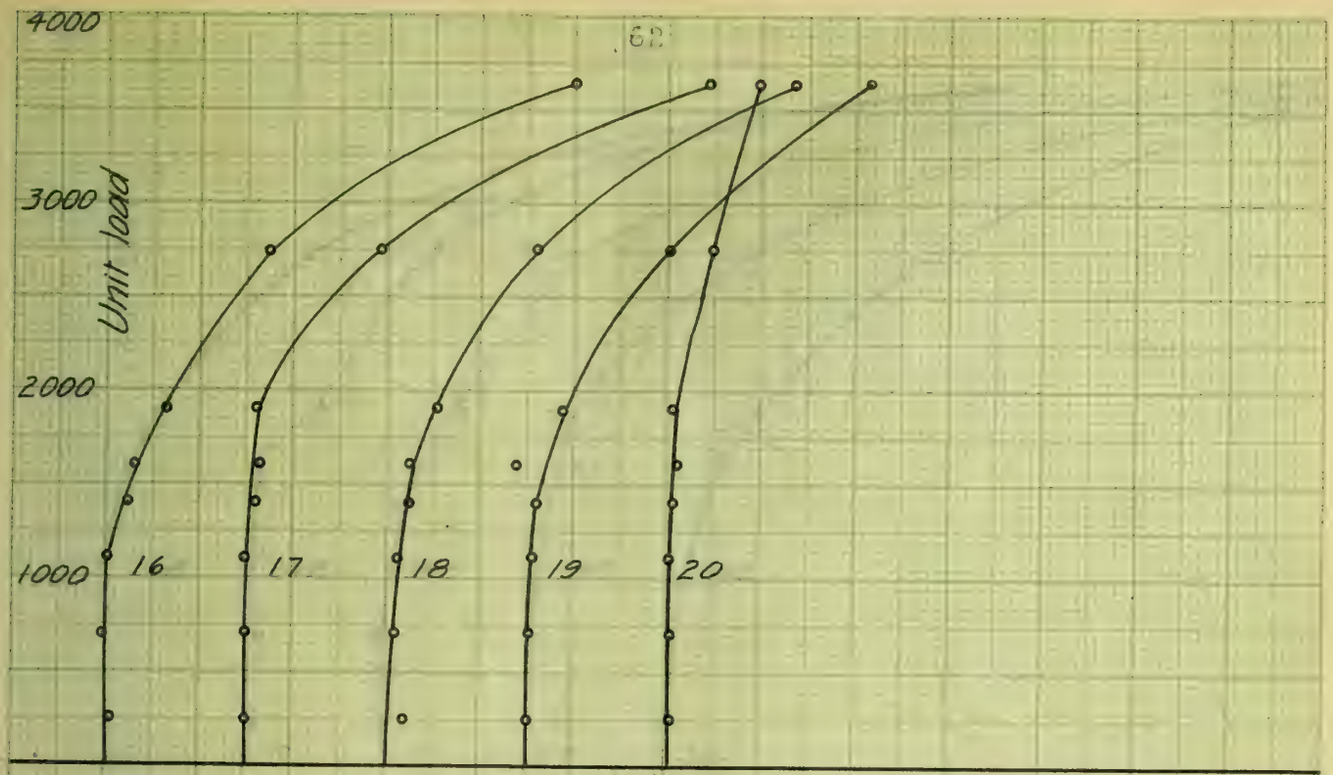

4000
3000
2000
1000
Unit load
11
12
13
14
15

COL. 8904

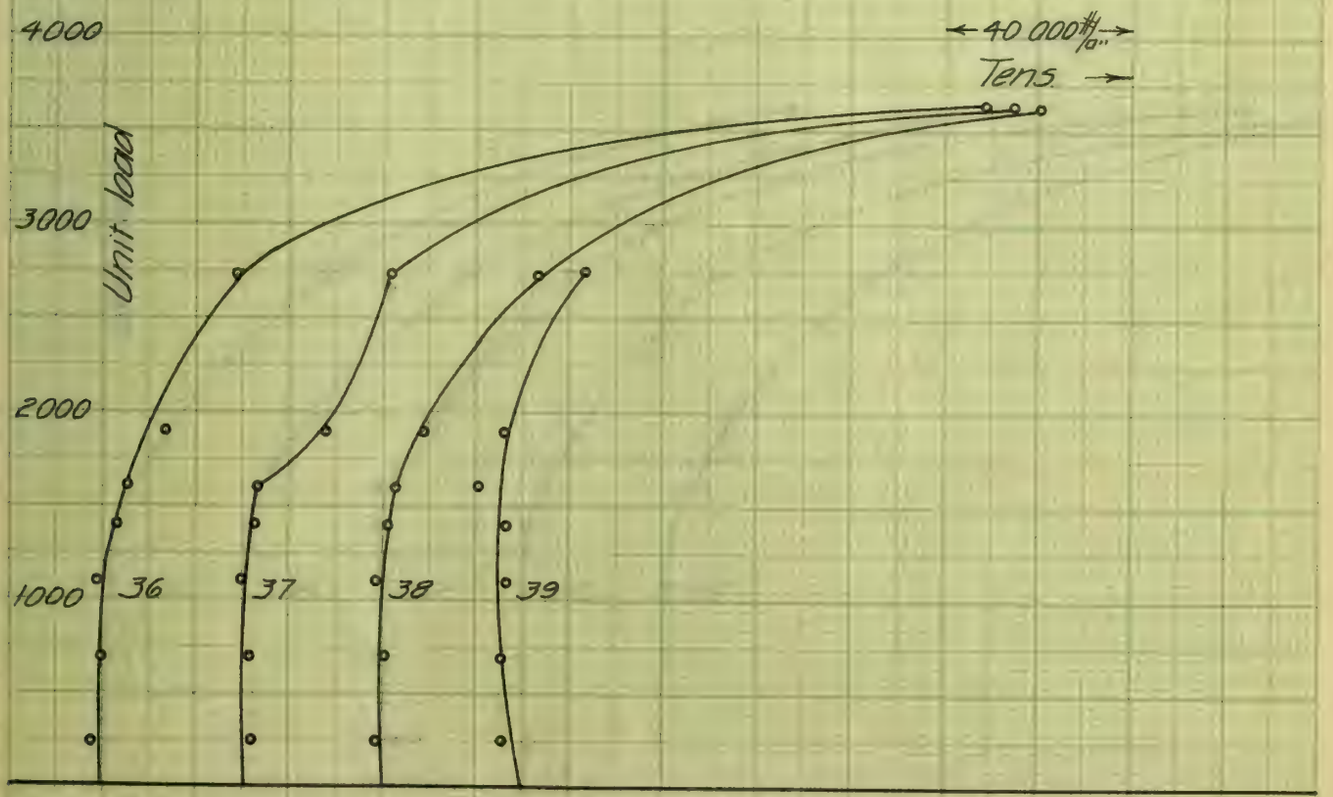

40000#/in²
Tens.
4000
3000
2000
1000
Unit load
31
32
33
34
35





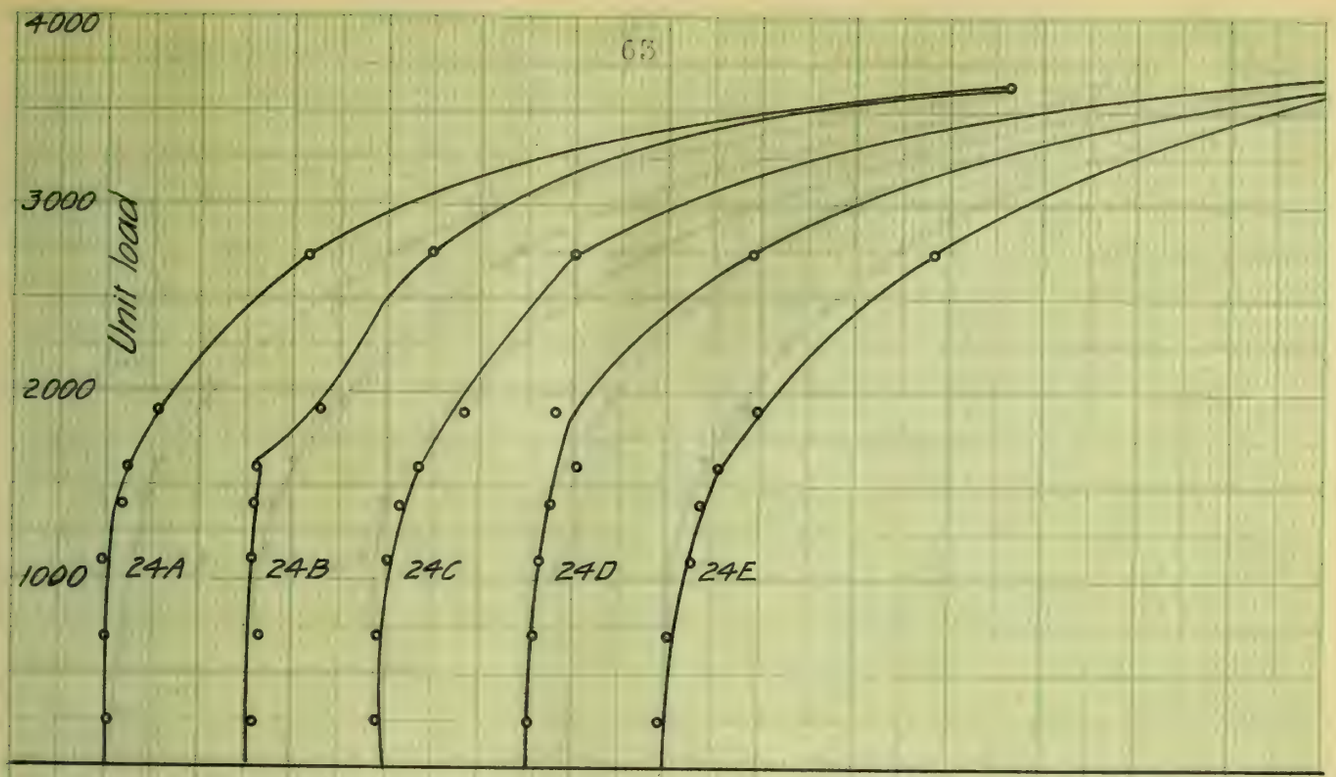

4000
3000
2000
1000
Unit load
16
17
18
19
20

COL. 8904

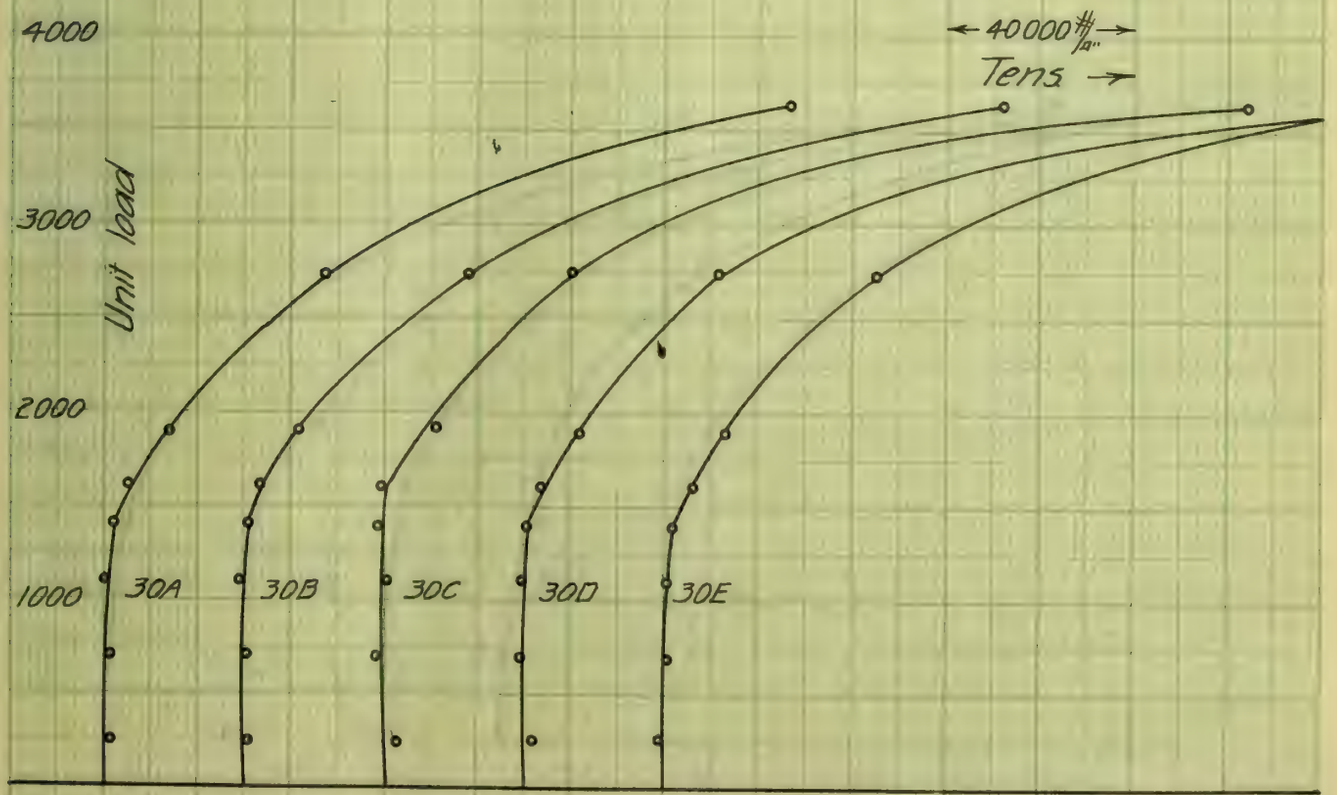

40 000#/□"
Tens.
4000
3000
2000
1000
Unit load
36
37
38
39





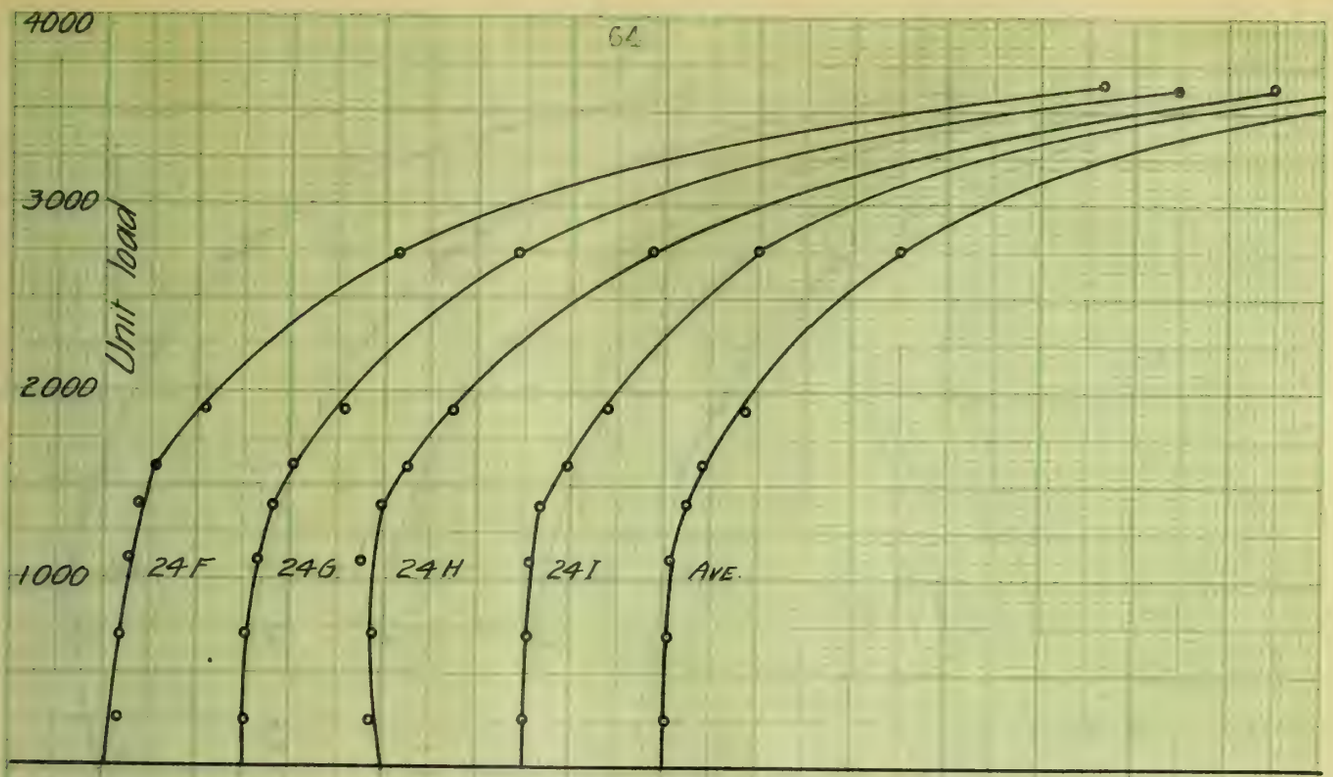

4000
3000
2000
1000
Unit load
24A
24B
24C
24D
24E

COL. 8904

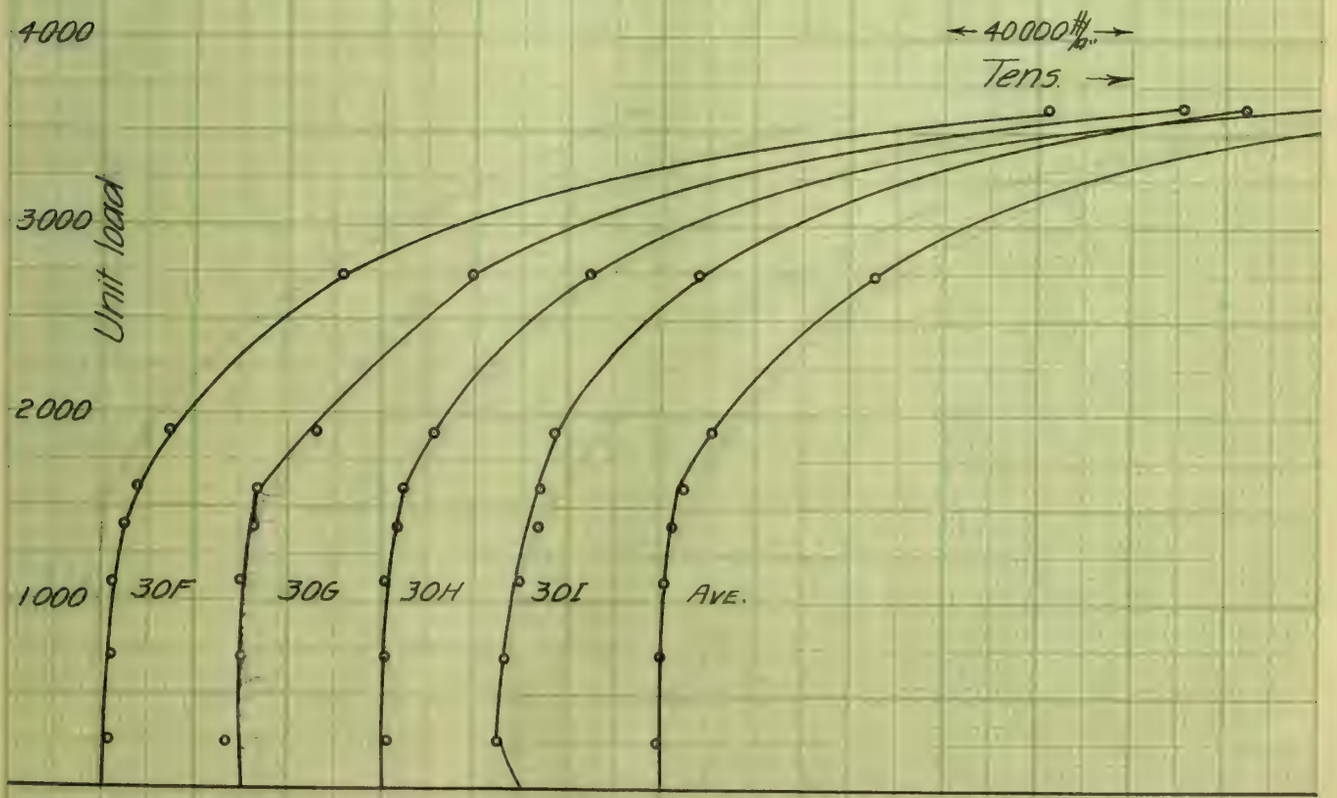

40000 #/in²
Tens
4000
3000
2000
1000
Unit load
30A
30B
30C
30D
30E

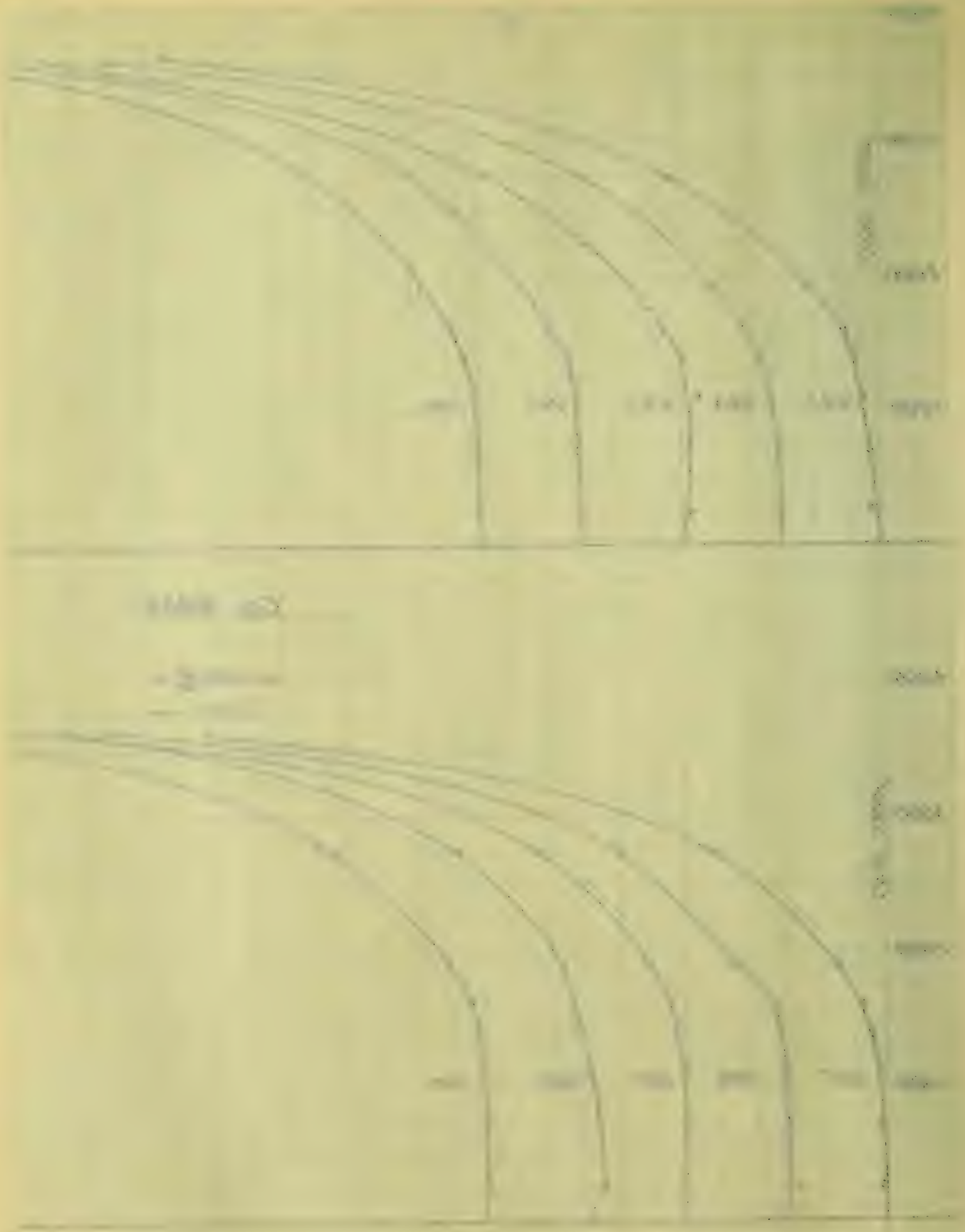


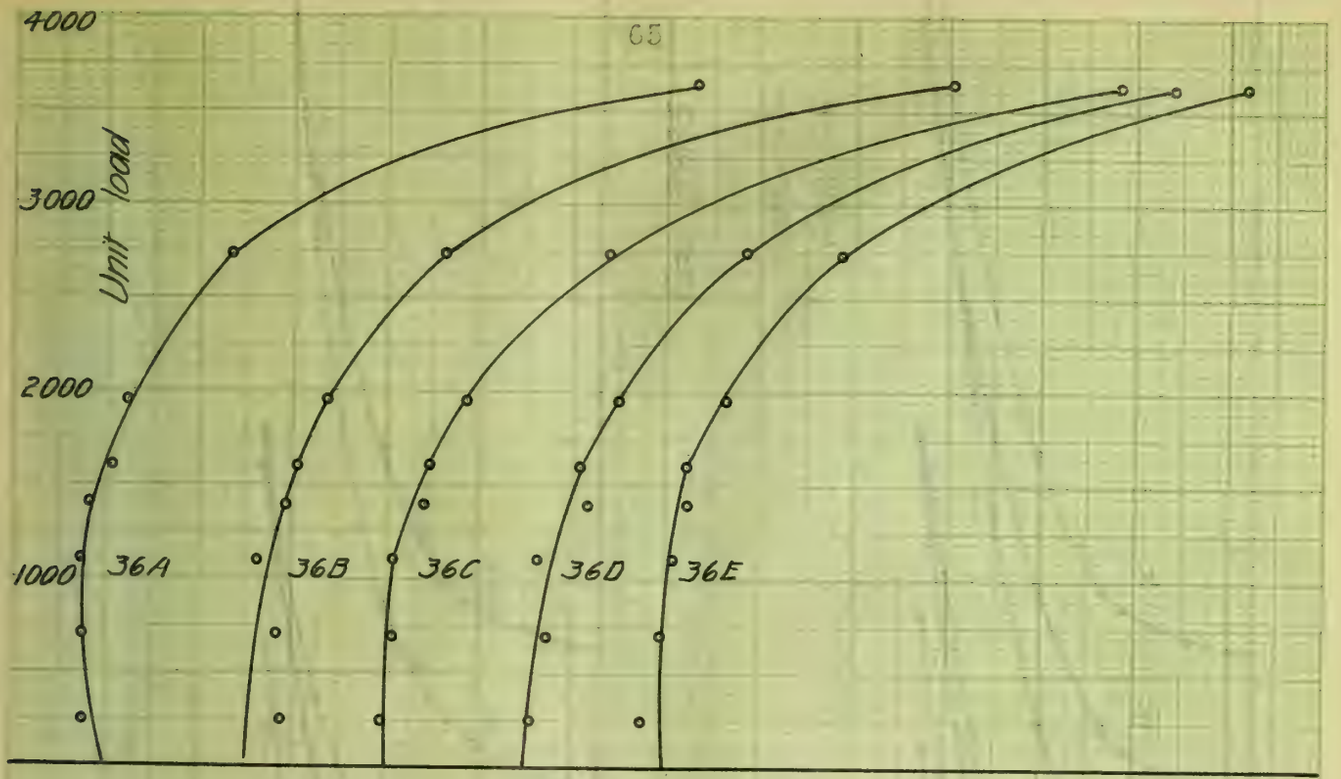



4000
3000
2000
1000
Unit load
24F
24G
24H
24I
Ave.

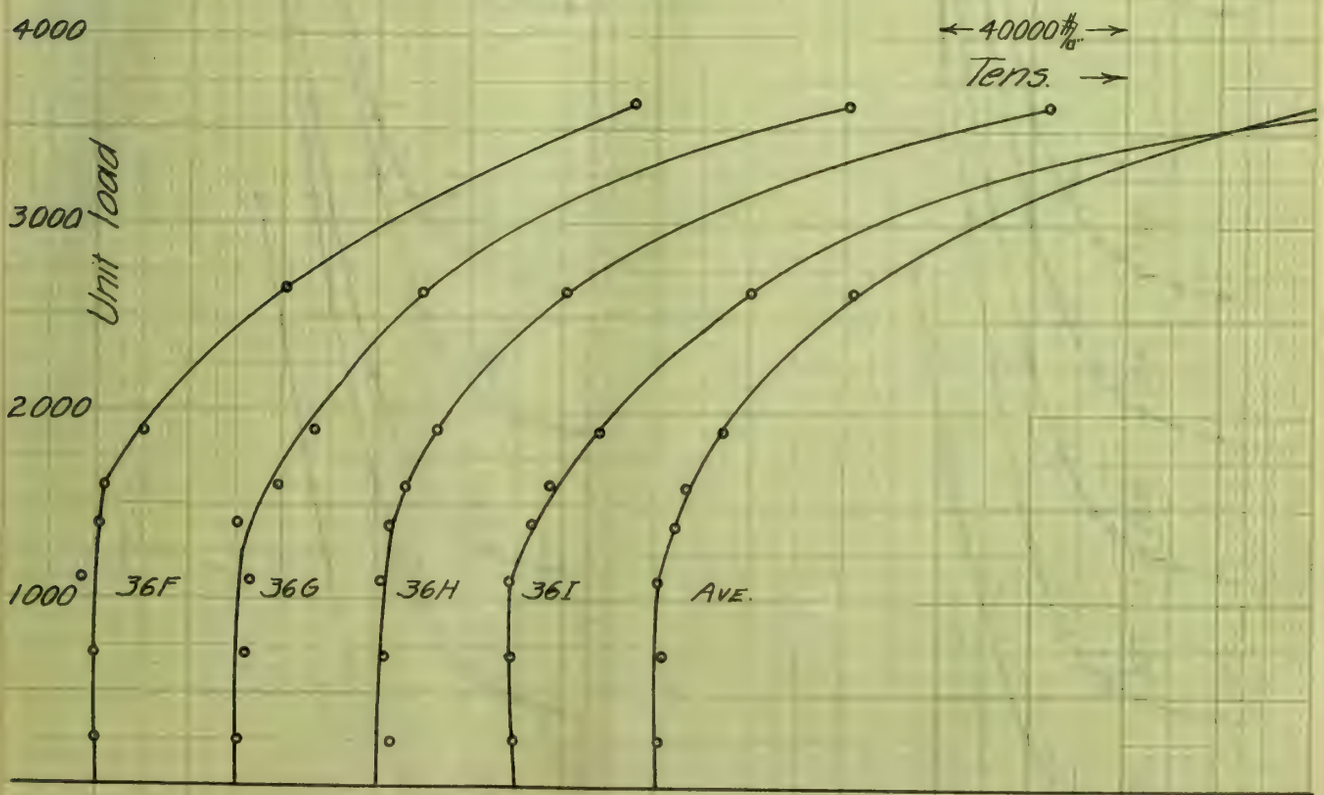
COL. 8904

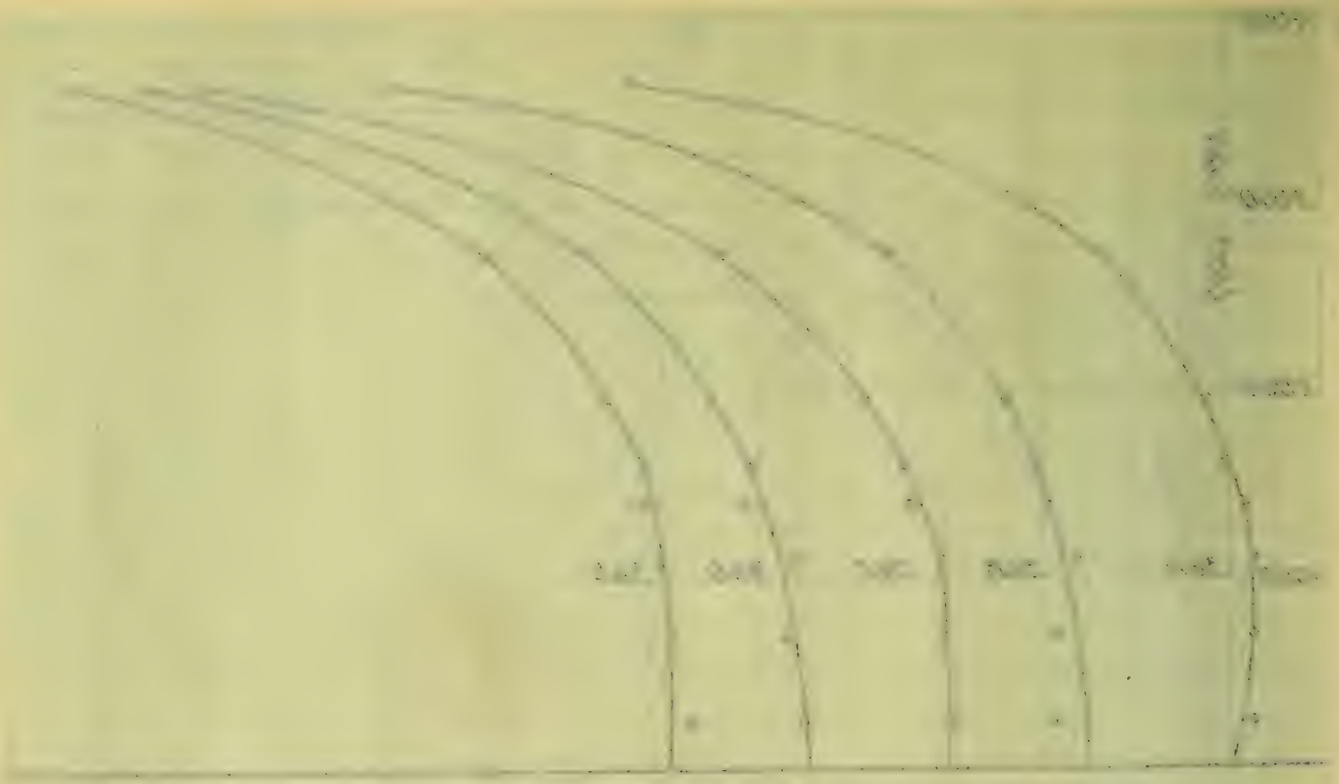

4000
3000
2000
1000
Unit load
40000 #/□"
Tens.
30F
30G
30H
30I
Ave.



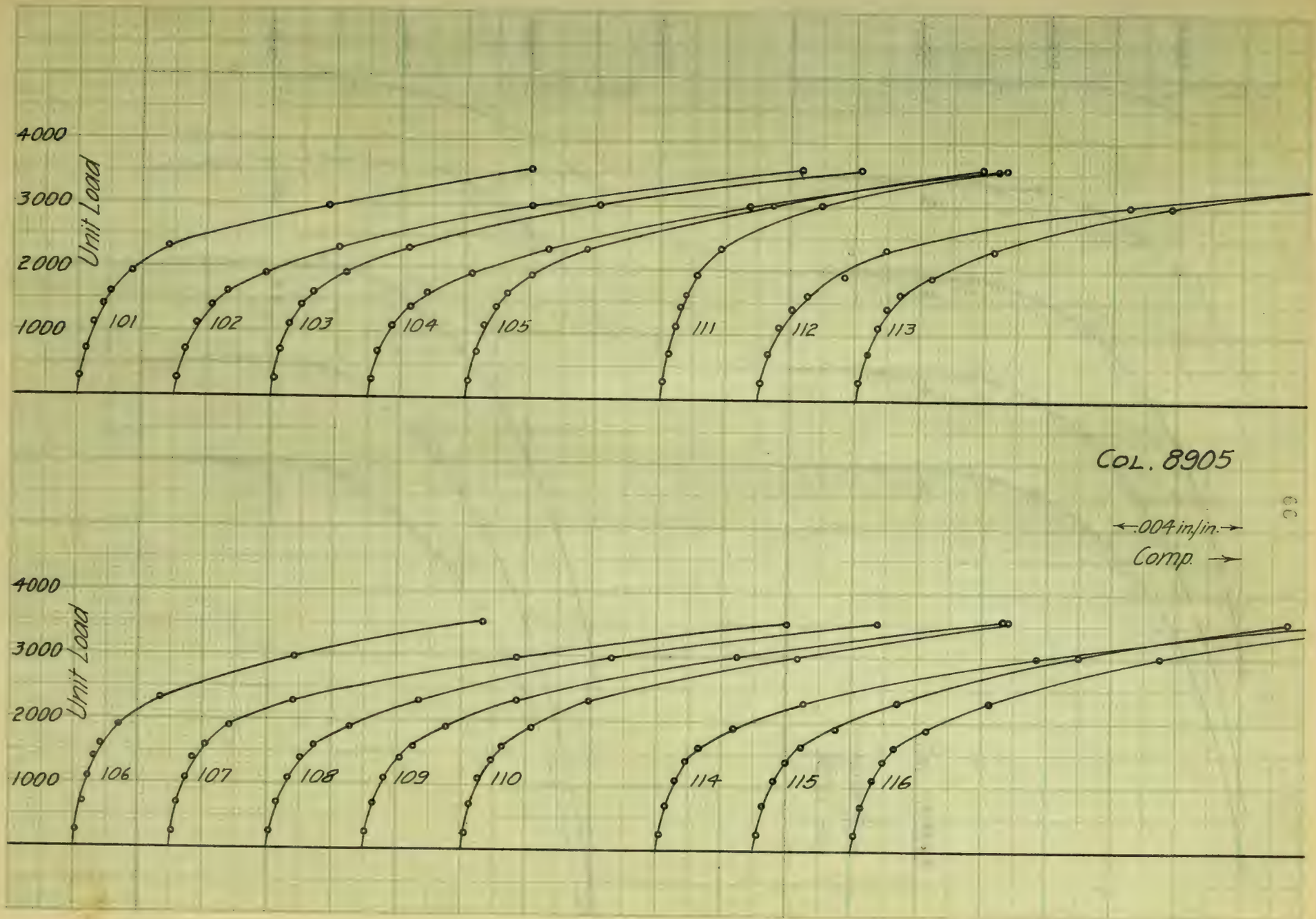

4000
3000
2000
1000
Unit load
36A
36B
36C
36D
36E

COL. 8904


4000
3000
2000
1000
Unit load
40000 #/in²
Tens.
36F
36G
36H
36I
AVE.

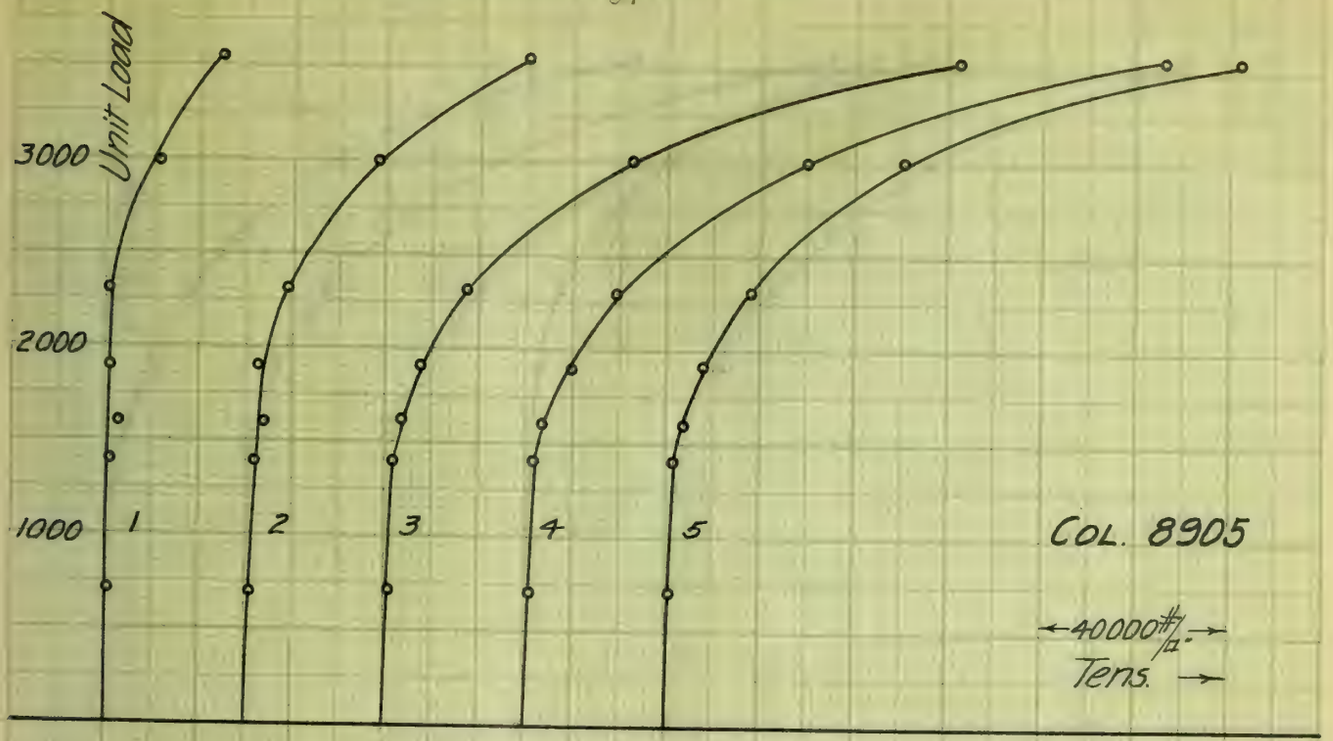


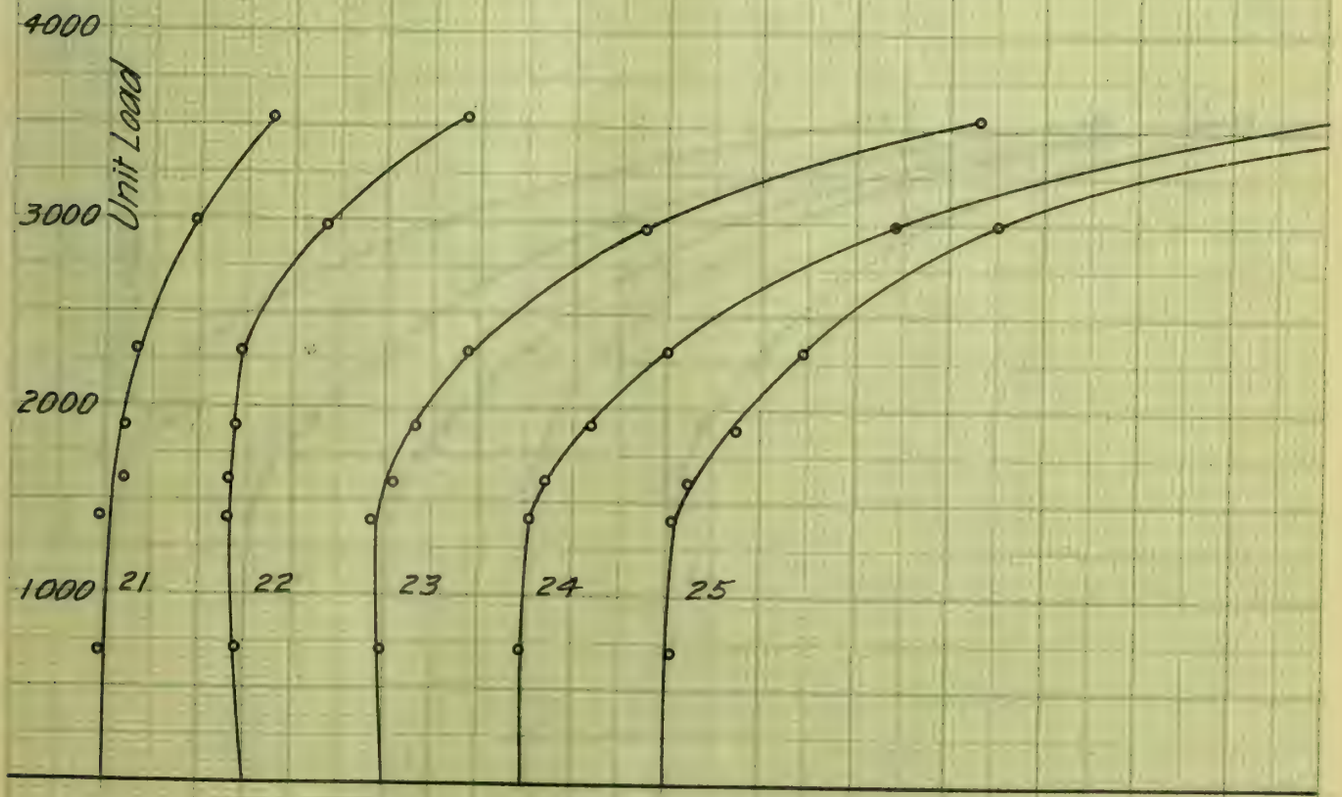


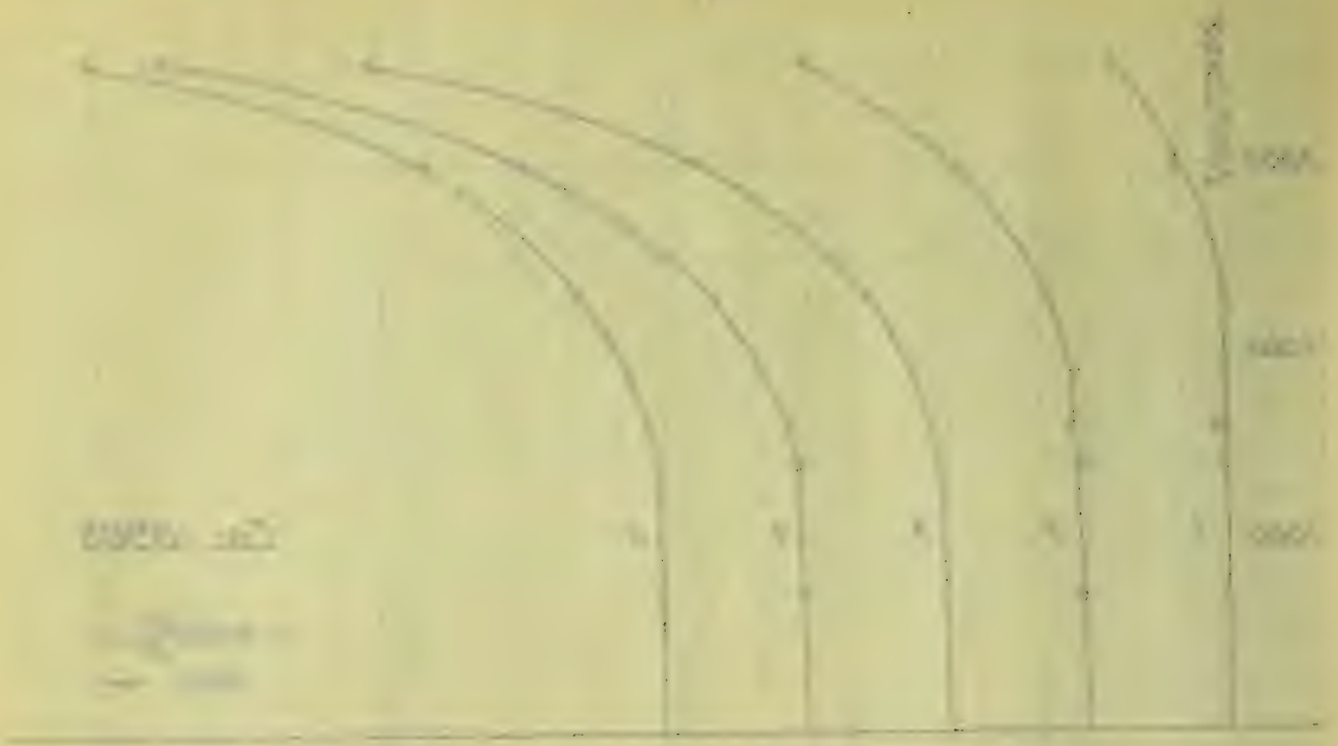

4000
3000
2000
1000
Unit Load
101
102
103
104
105
111
112
113
Col. 8905
←.004 in/in.→
Comp. →
4000
3000
2000
1000
Unit Load
106
107
108
109
110
114
115
116

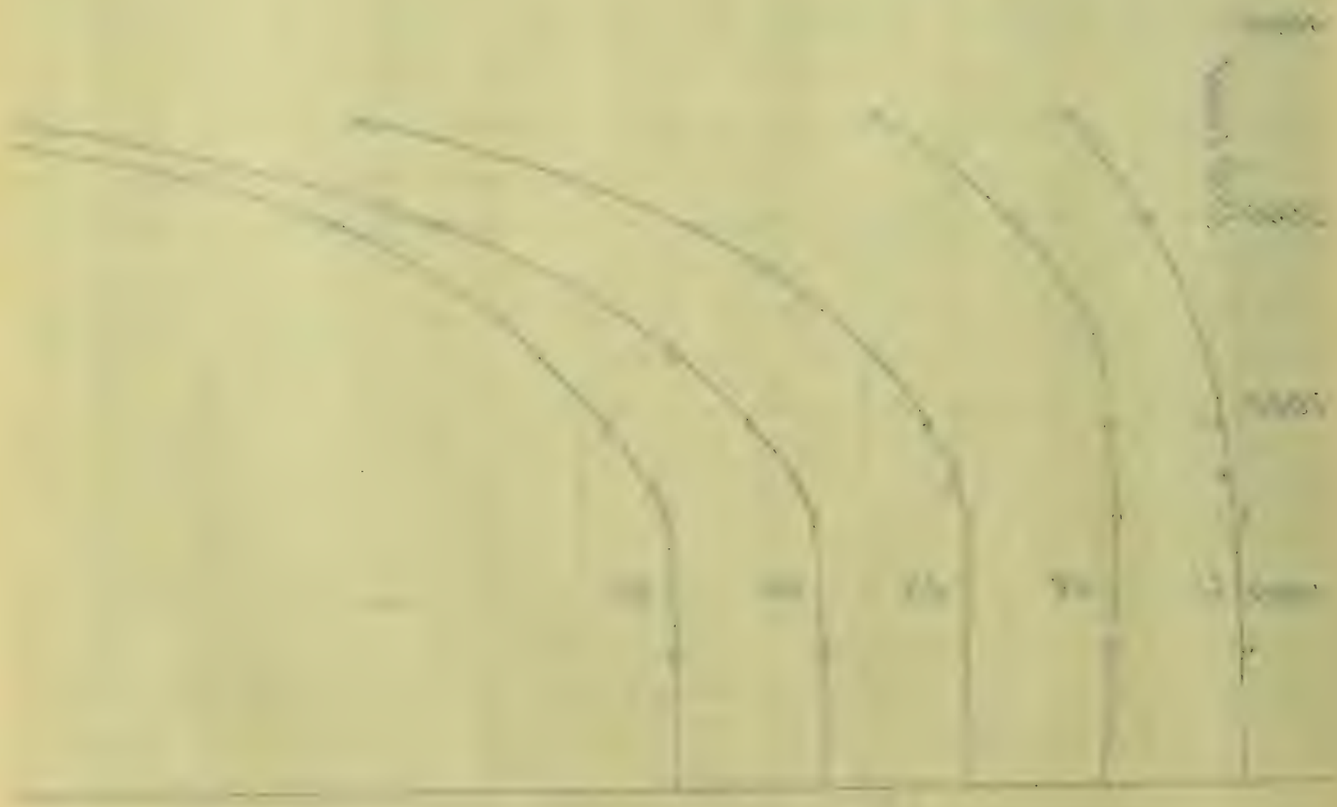


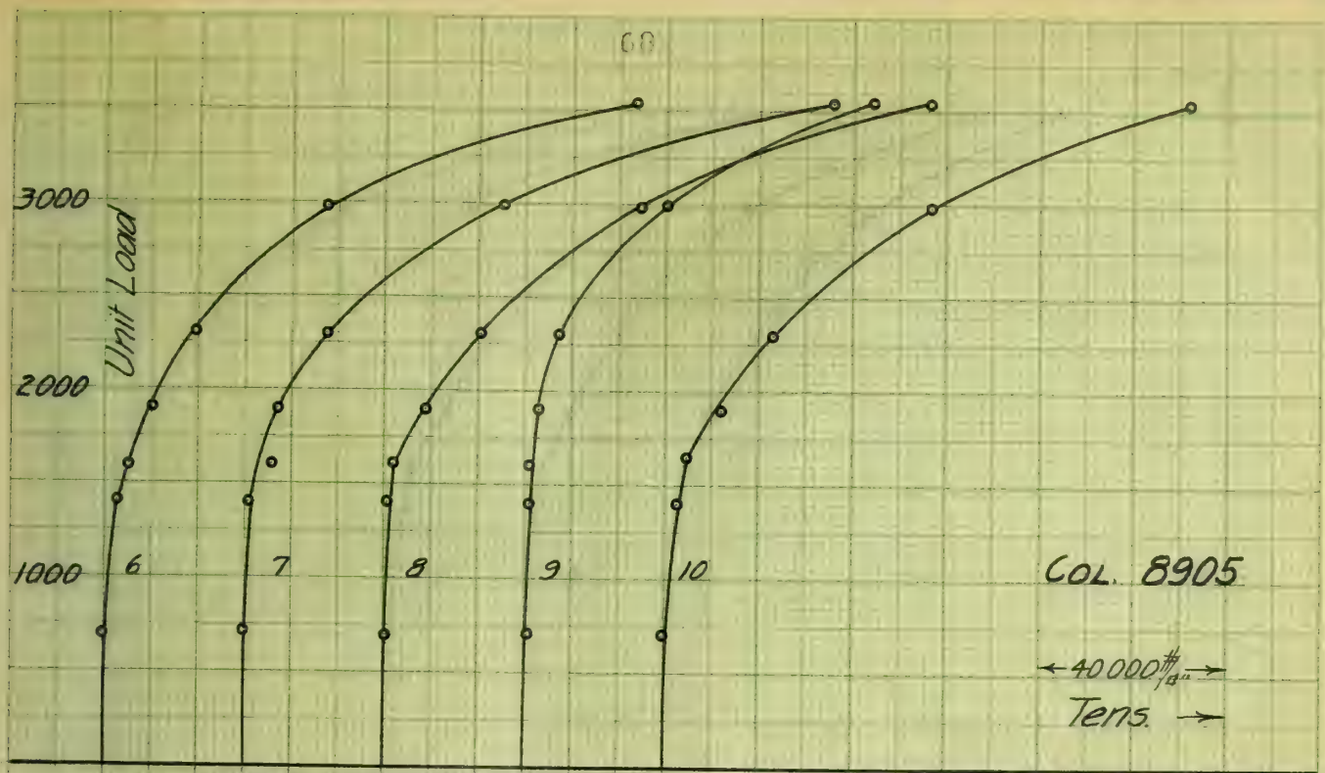


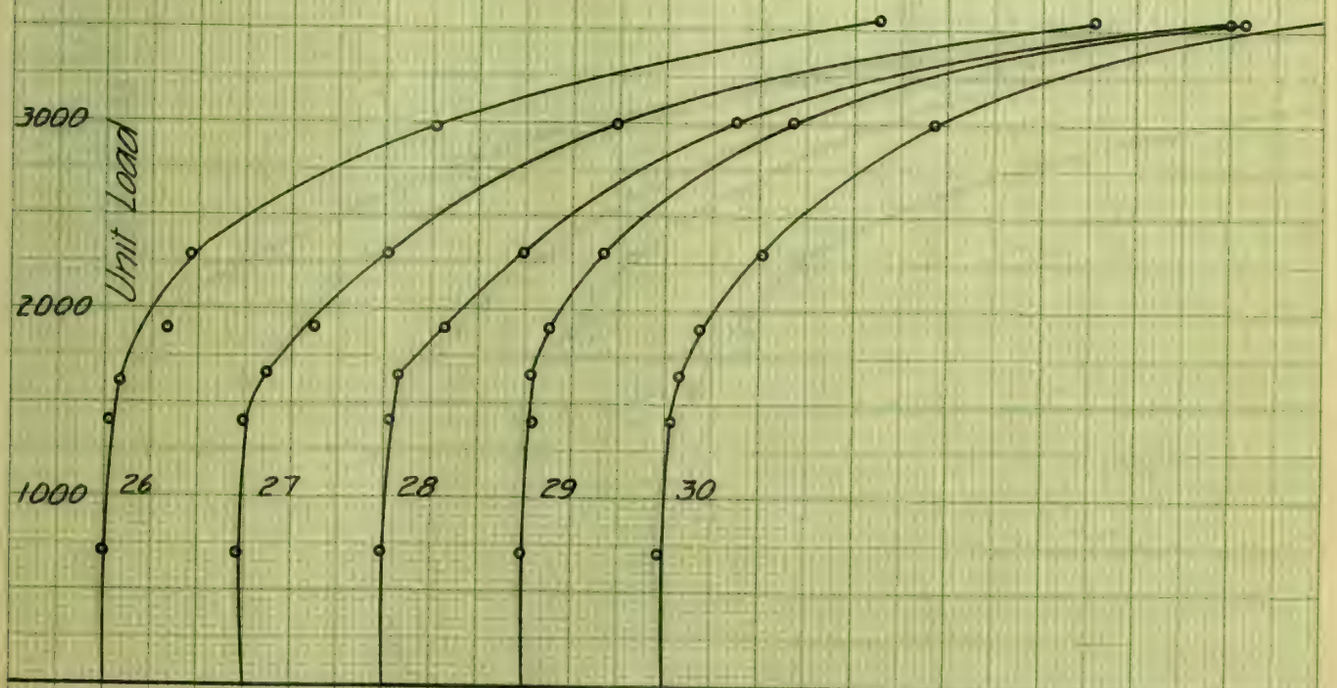

Unit Load
3000
2000
1000
1
2
3
4
5
COL. 8905
←40000#/□"→
Tens. →


4000
Unit Load
3000
2000
1000
21
22
23
24
25



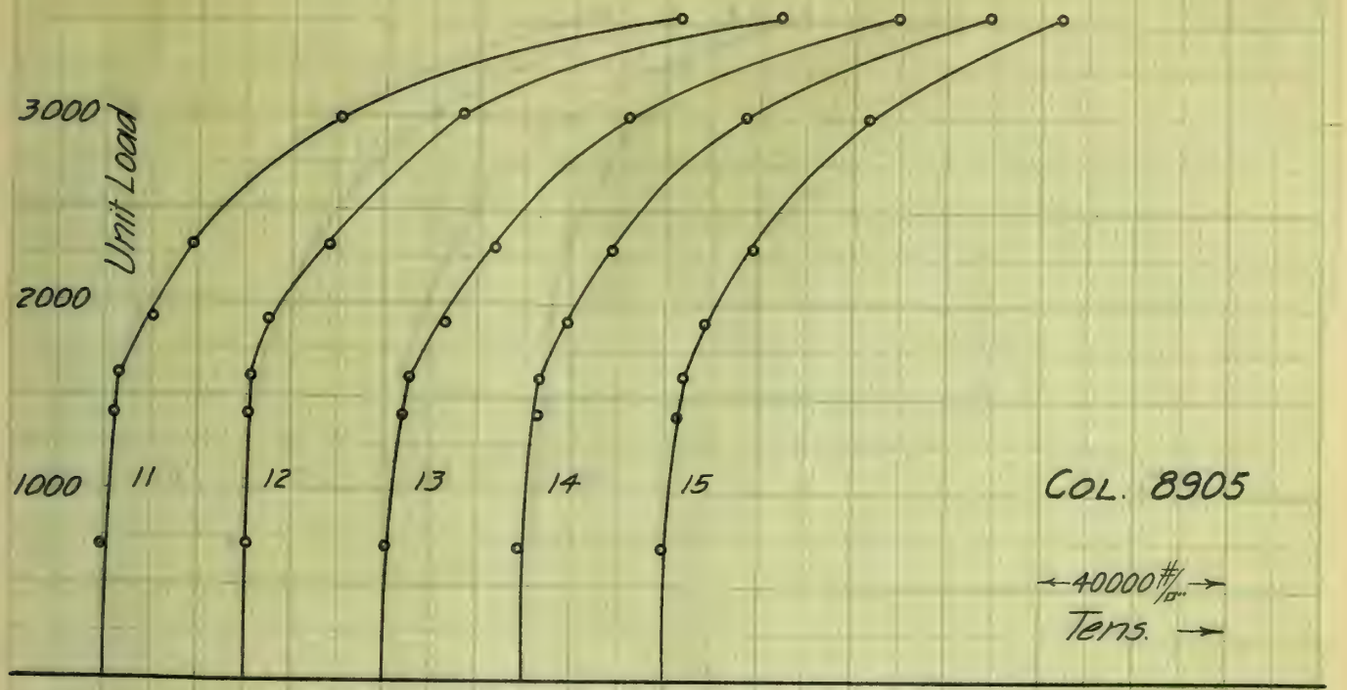


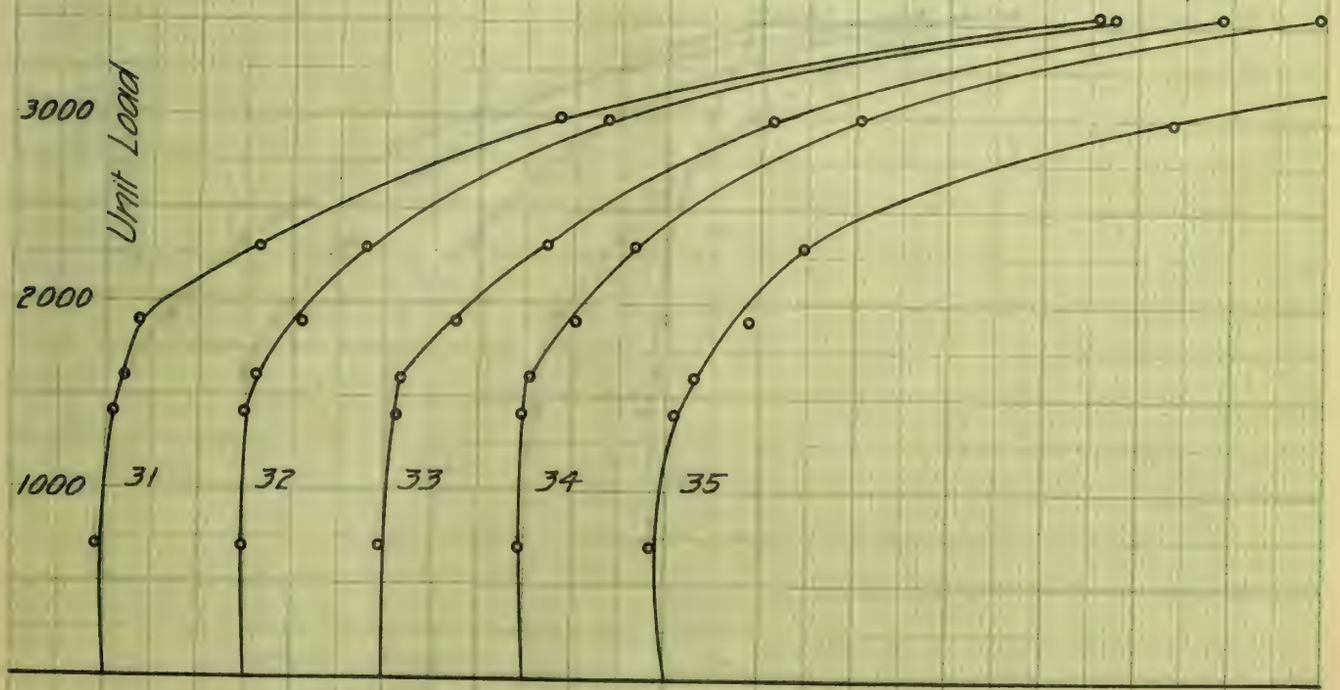

3000
2000
1000
Unit Load
6
7
8
9
10
COL. 8905
←40000#/in→
Tens. →


3000
2000
1000
Unit Load
26
27
28
29
30



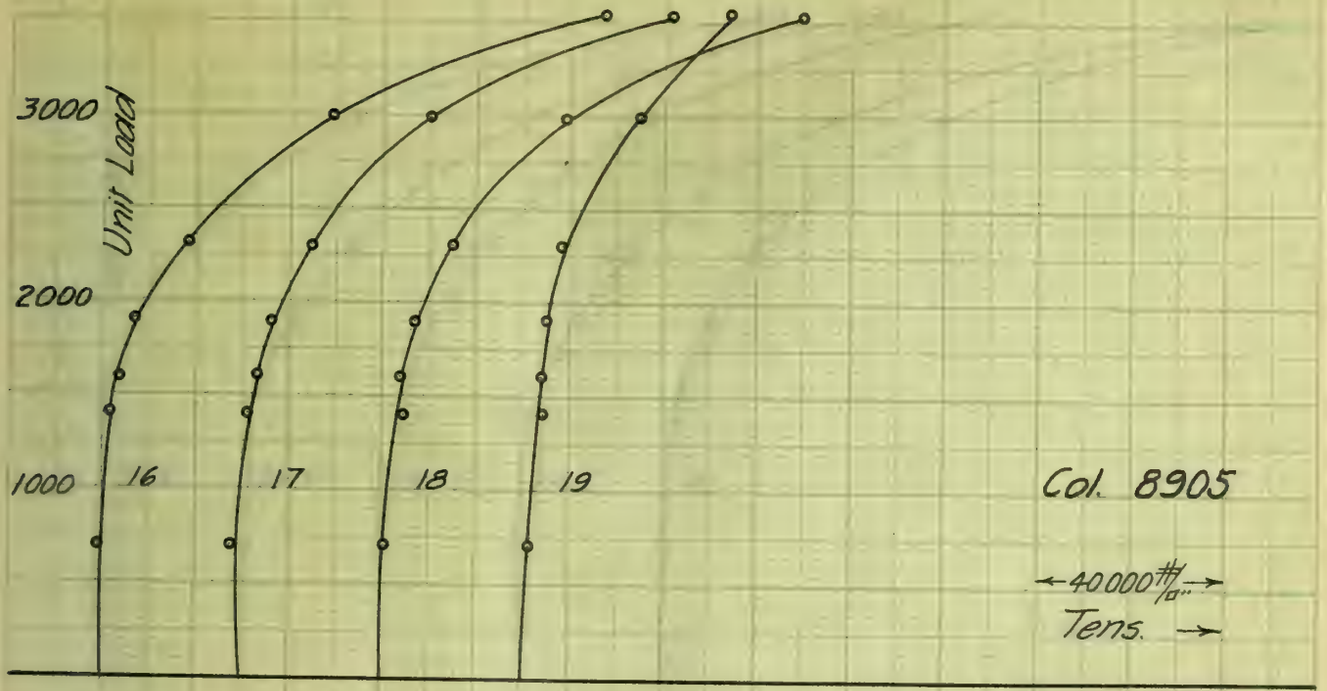


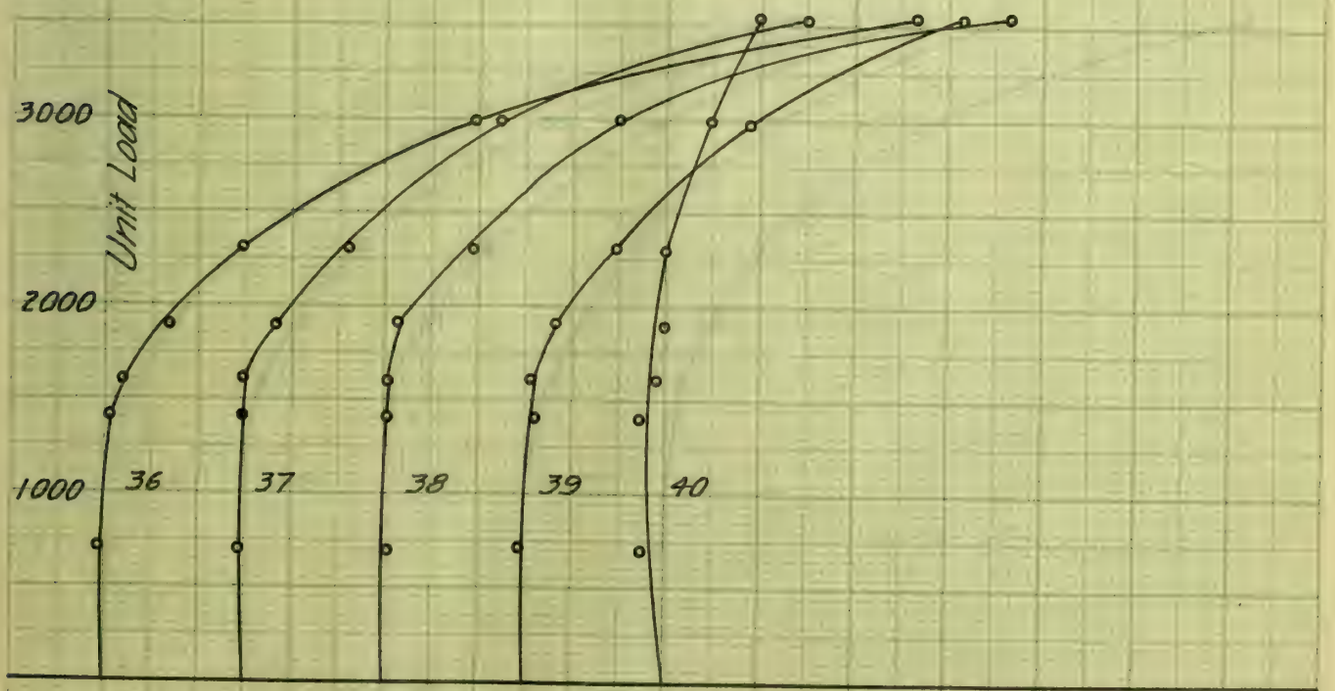

3000
Unit Load
2000
1000
11
12
13
14
15
COL. 8905
←40000#/in.→
Tens. →


3000
Unit Load
2000
1000
31
32
33
34
35



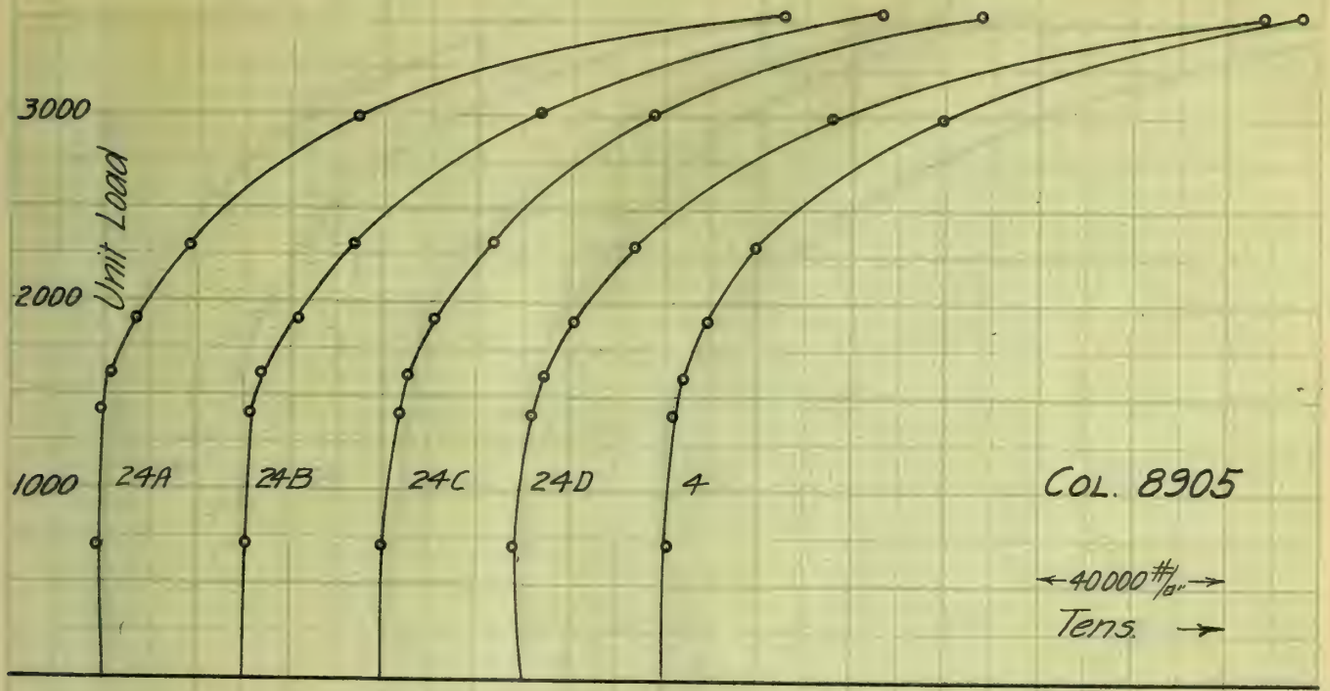


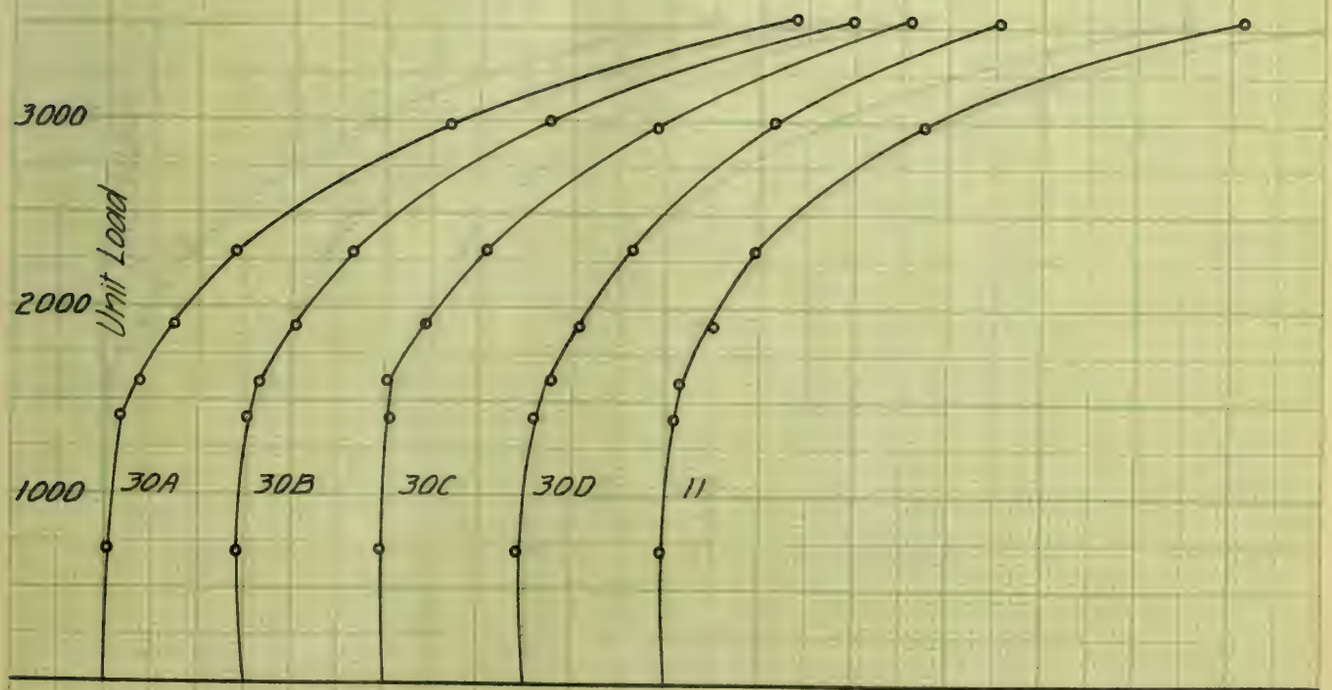

3000
Unit Load
2000
1000
16
17
18
19
Col. 8905
←40000#/□"→
Tens. →


3000
Unit Load
2000
1000
36
37
38
39
40



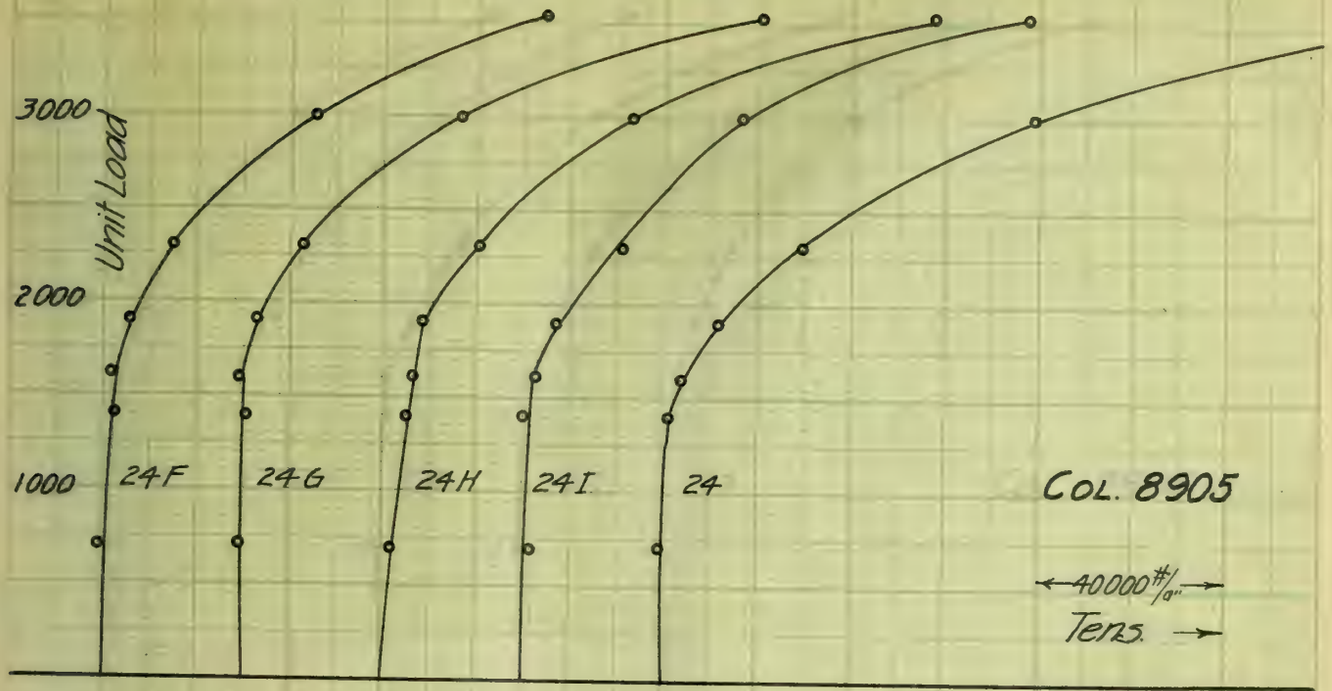


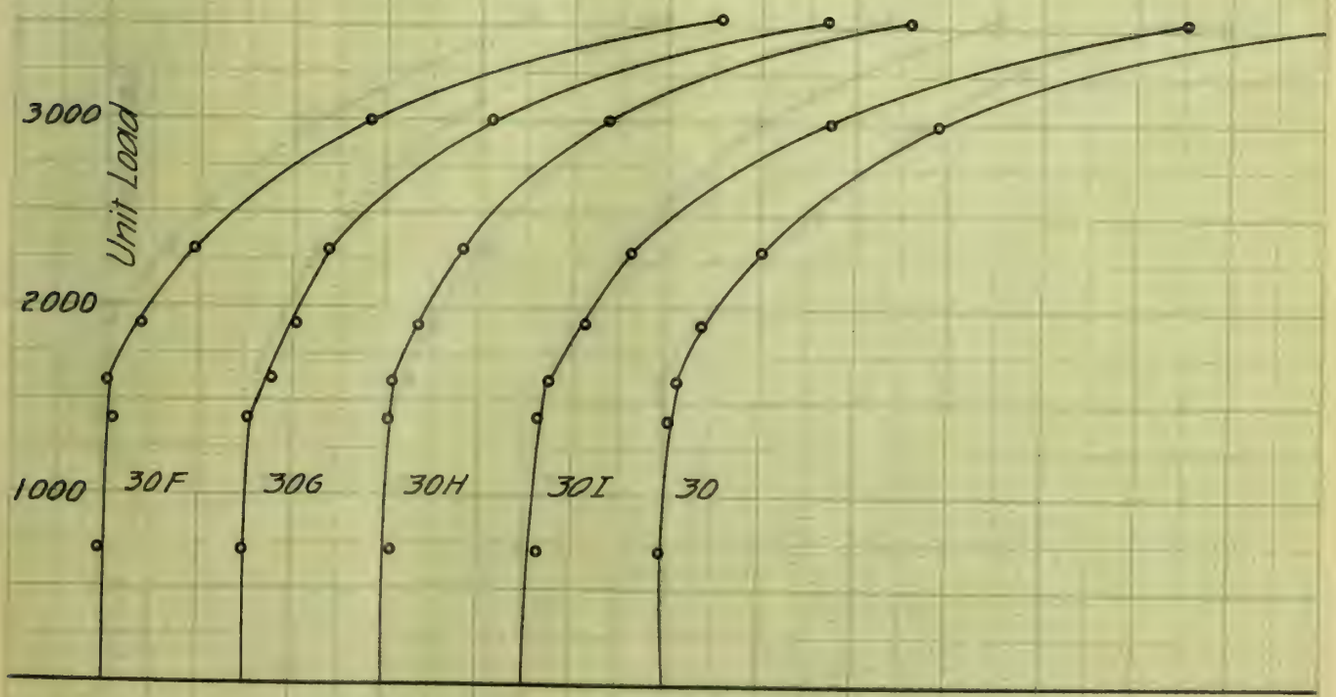

3000
2000
1000
Unit Load
24A
24B
24C
24D
4
COL. 8905
←40000 #/in²→
Tens. →


3000
2000
1000
Unit Load
30A
30B
30C
30D
11

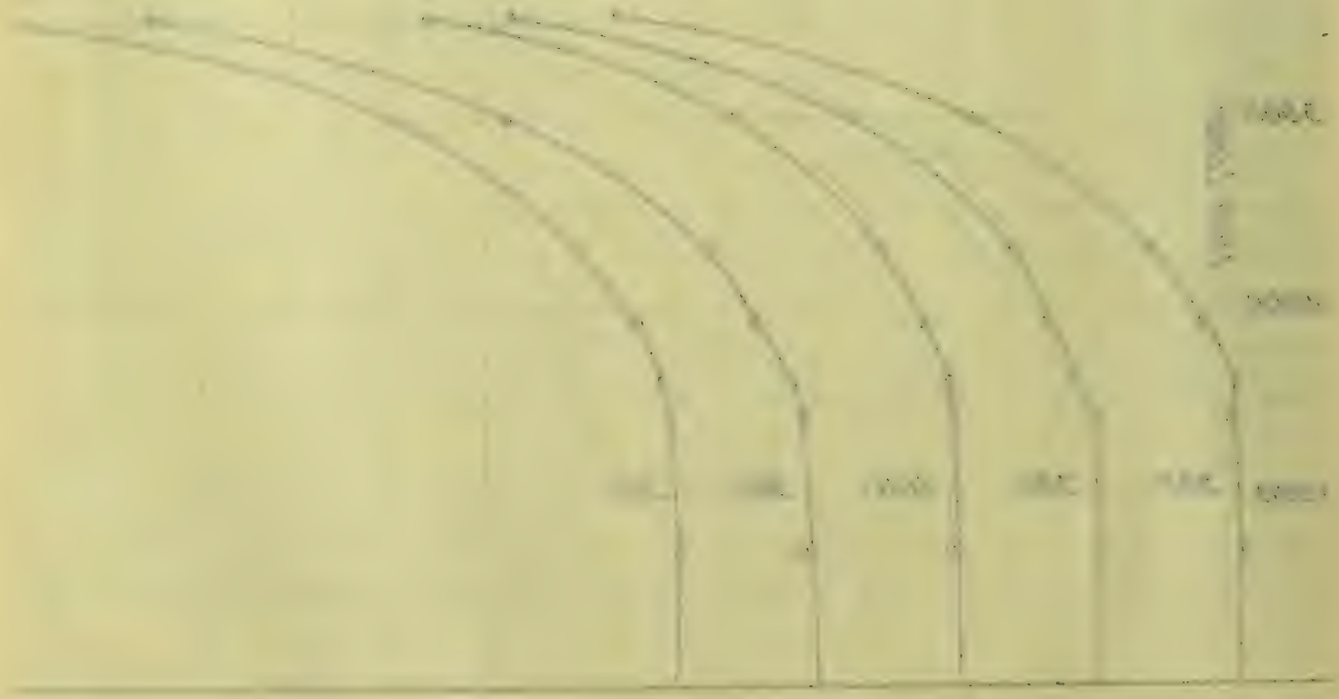


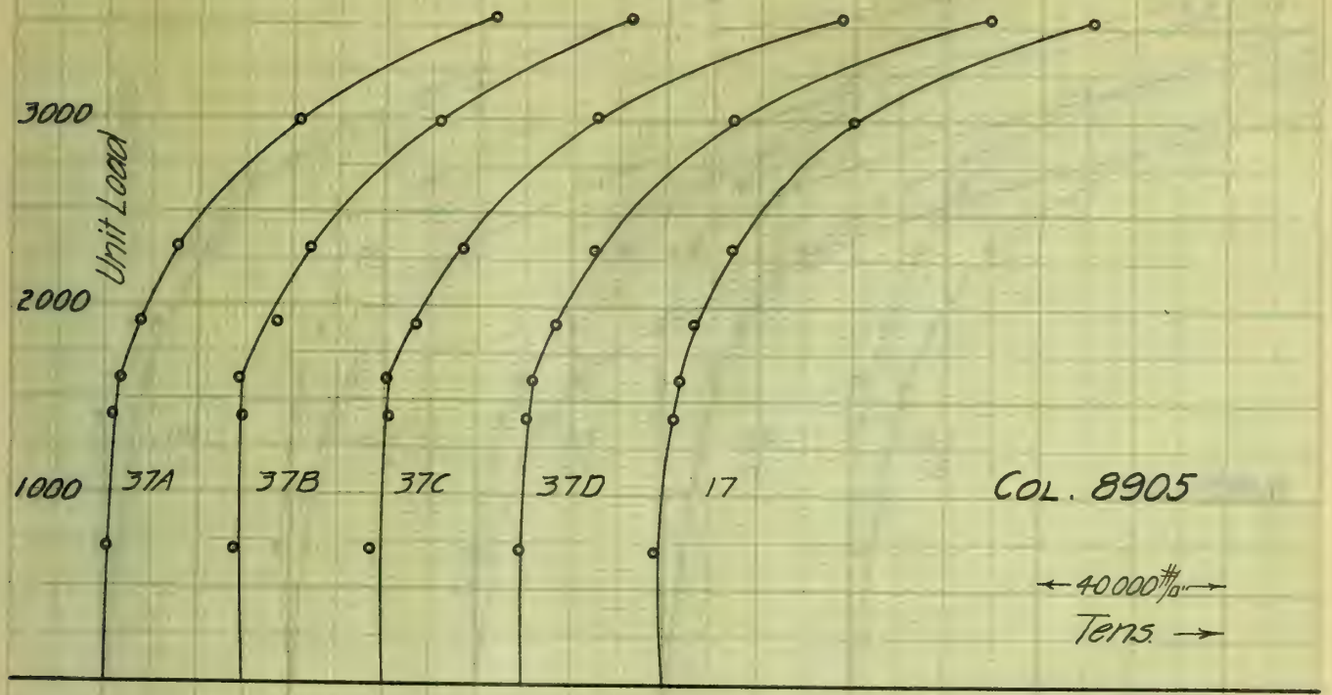


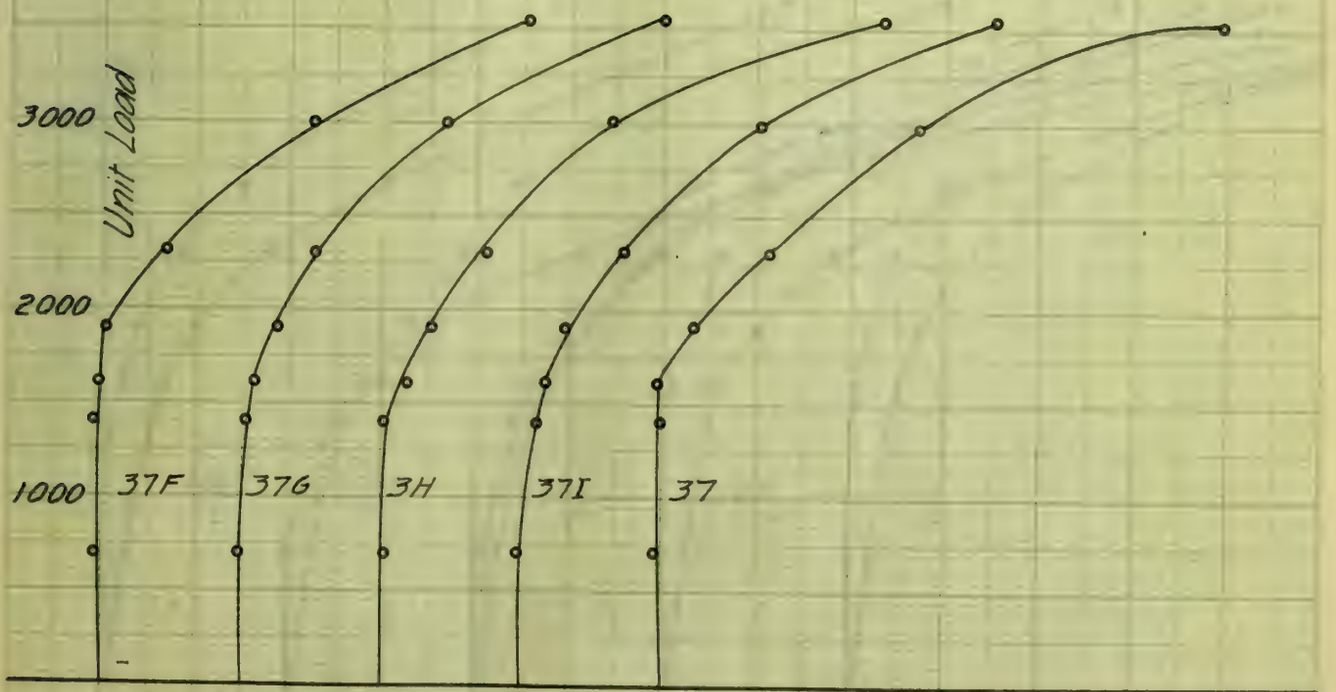

3000
Unit Load
2000
1000
24F
24G
24H
24I
24
COL. 8905
←40000#/□"→
Tens. →


3000
Unit Load
2000
1000
30F
30G
30H
30I
30



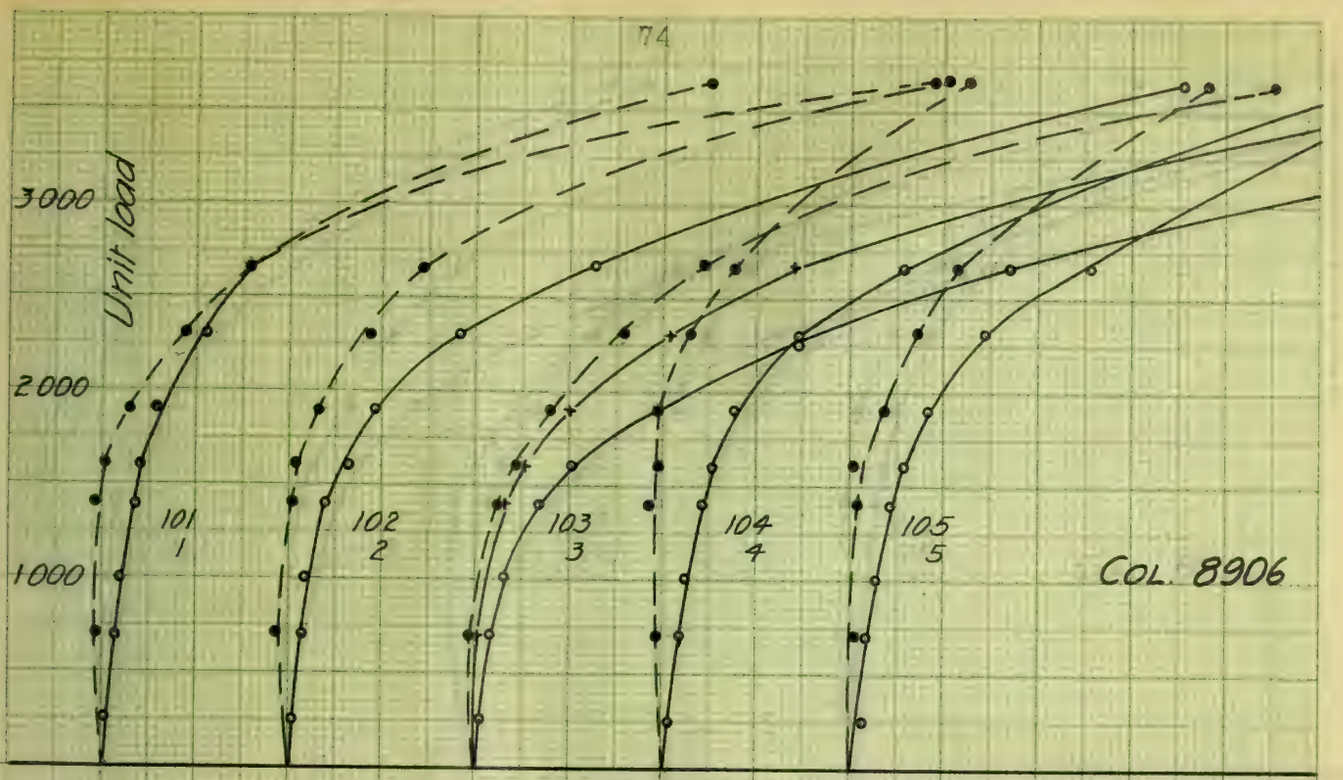



3000
Unit Load
2000
1000
37A
37B
37C
37D
17
COL. 8905
40000#/in.
Tens.

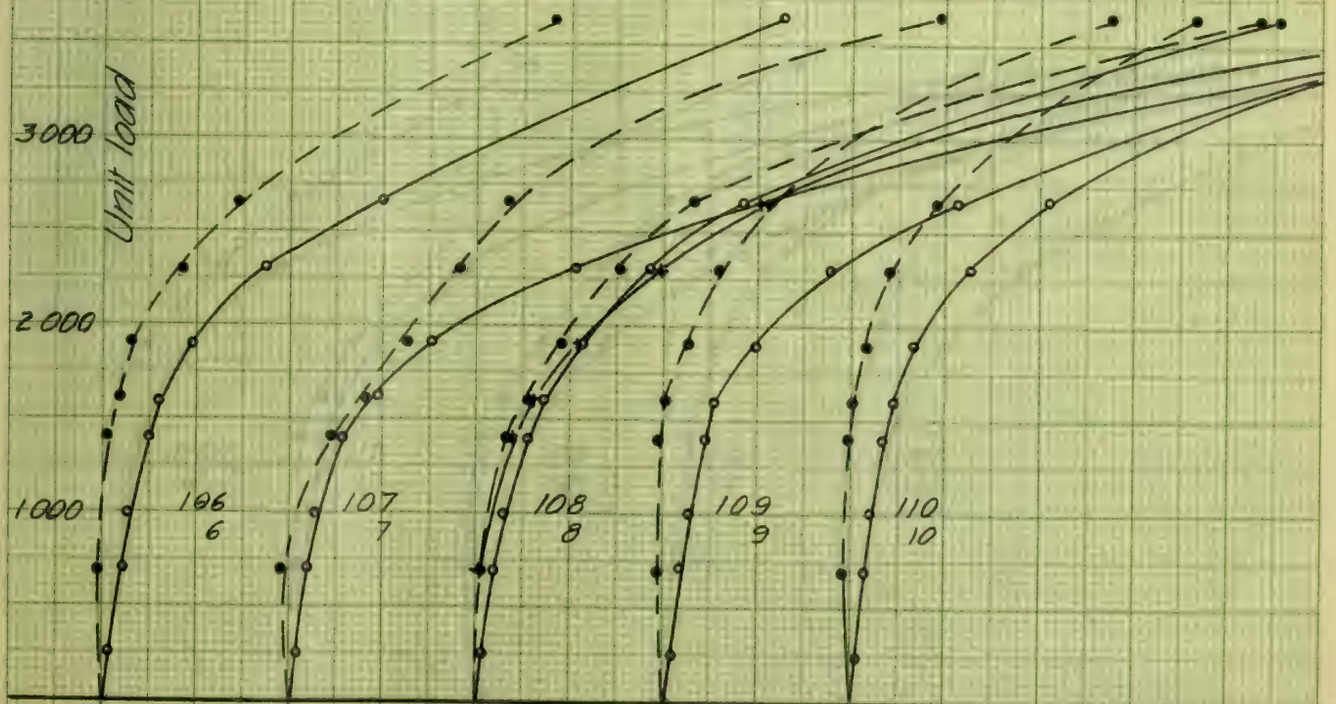

3000
Unit Load
2000
1000
37F
37G
3H
37I
37





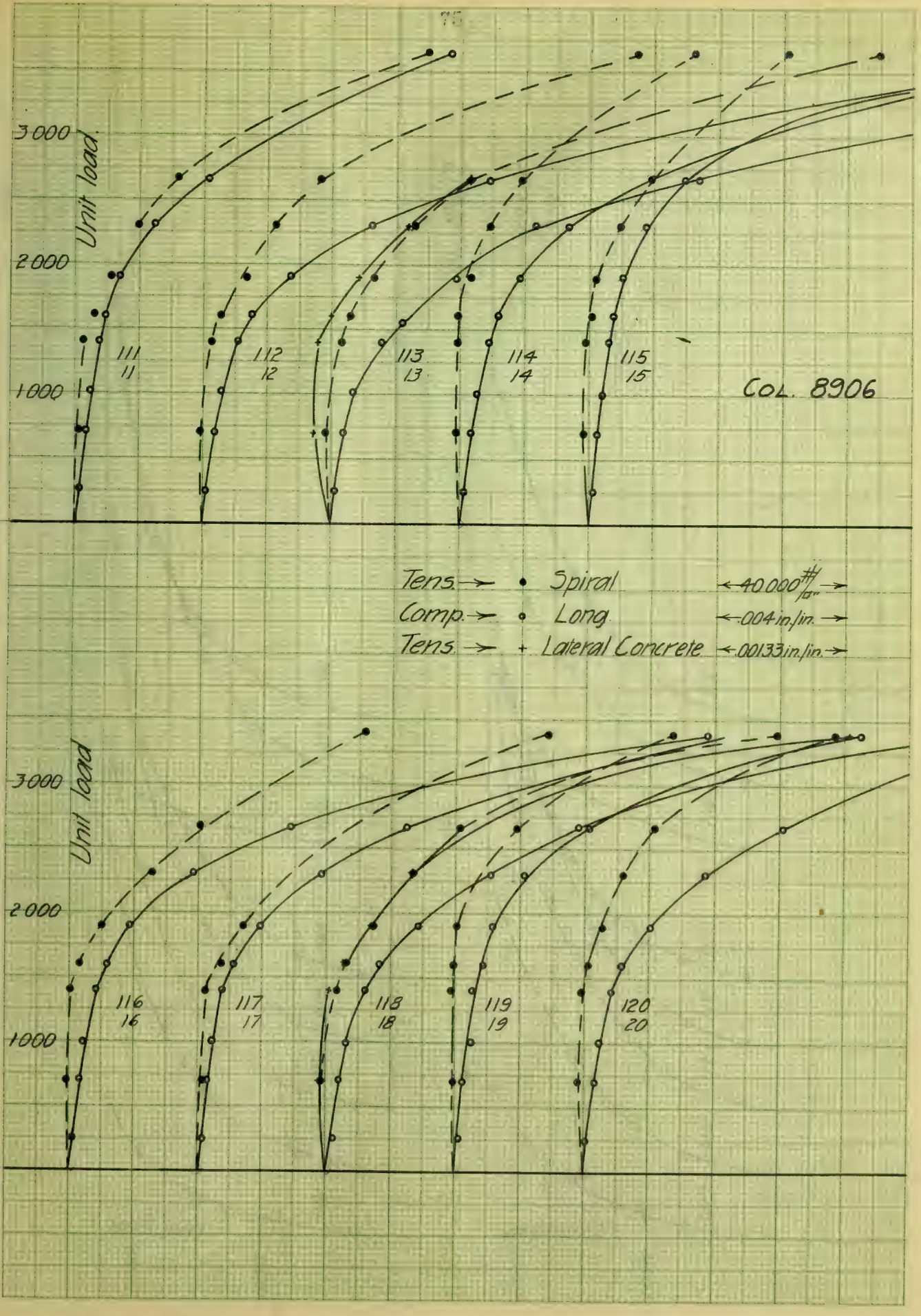


Tens. → • Spiral ← 40000 #/in² →
Comp. → ○ Long. ← .004 in./in. →
Tens. → + Lateral Concrete ← .00133 in./in. →



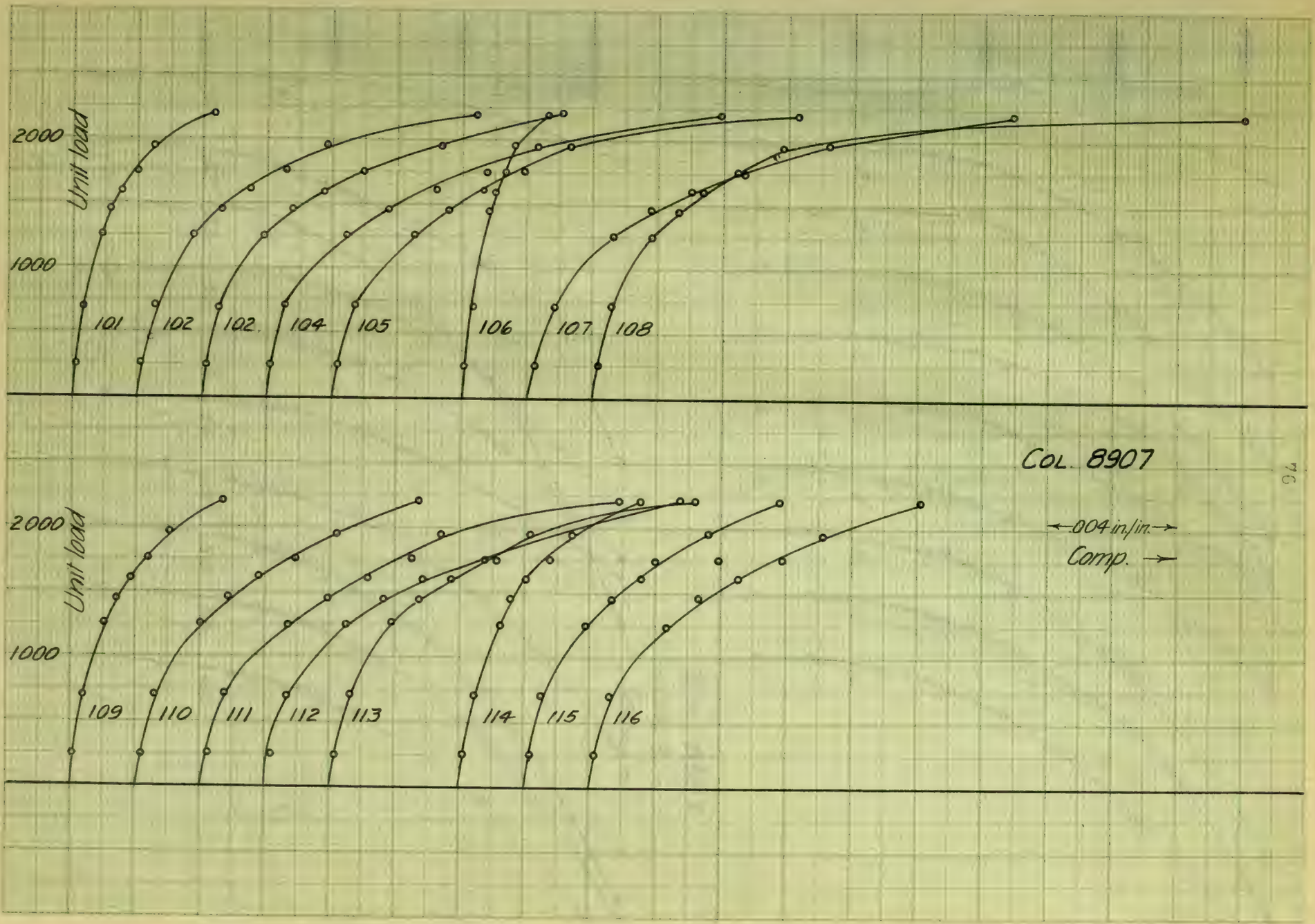




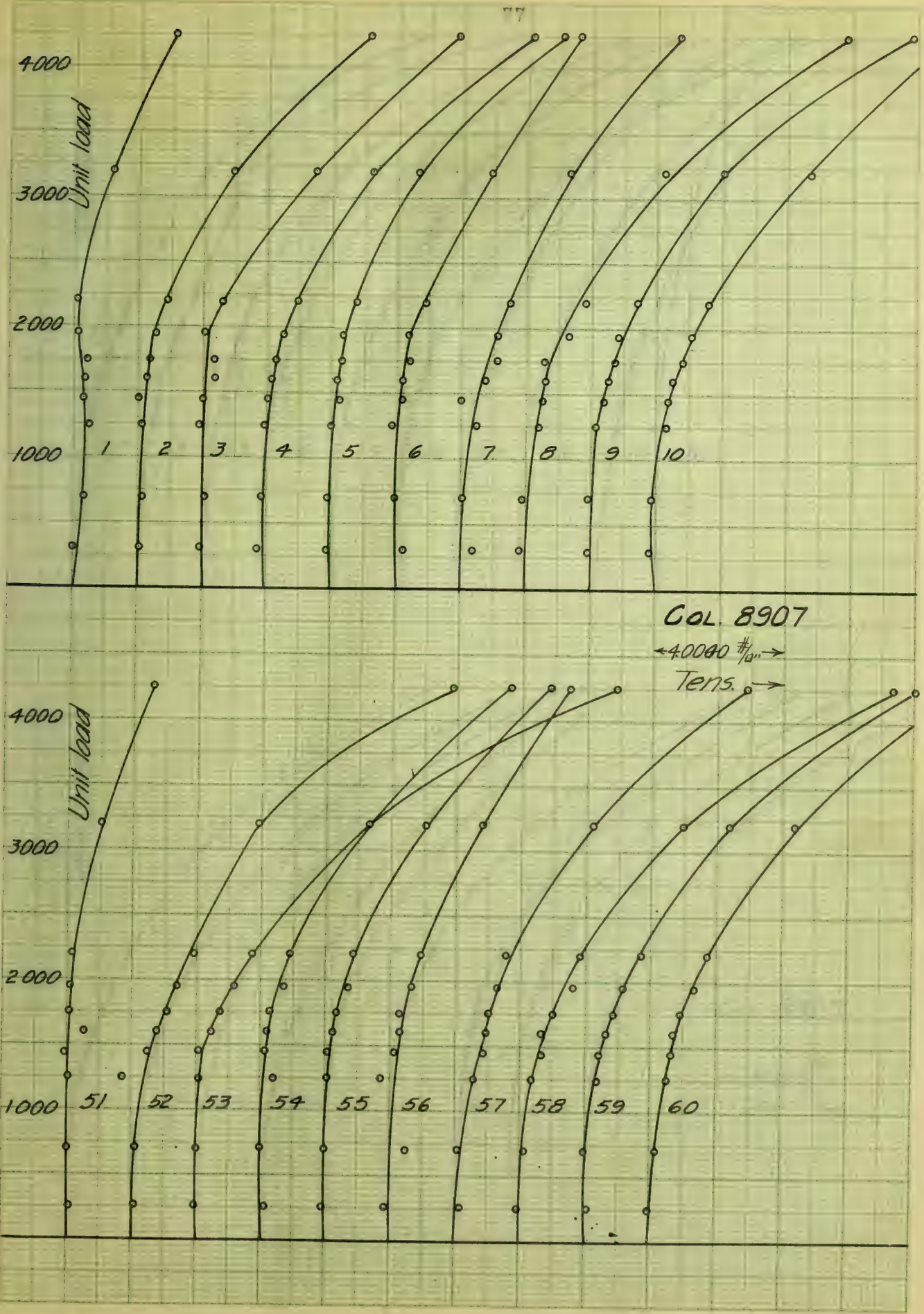

3000
2000
1000
Unit load.
111
11
112
12
113
13
114
14
115
15
COL. 8906
Tens. → • Spiral ← 40.000 #/in. →
Comp. → ○ Long. ← .004 in./in. →
Tens. → + Lateral Concrete ← .00133 in./in. →
3000
2000
1000
Unit load
116
16
117
17
118
18
119
19
120
20

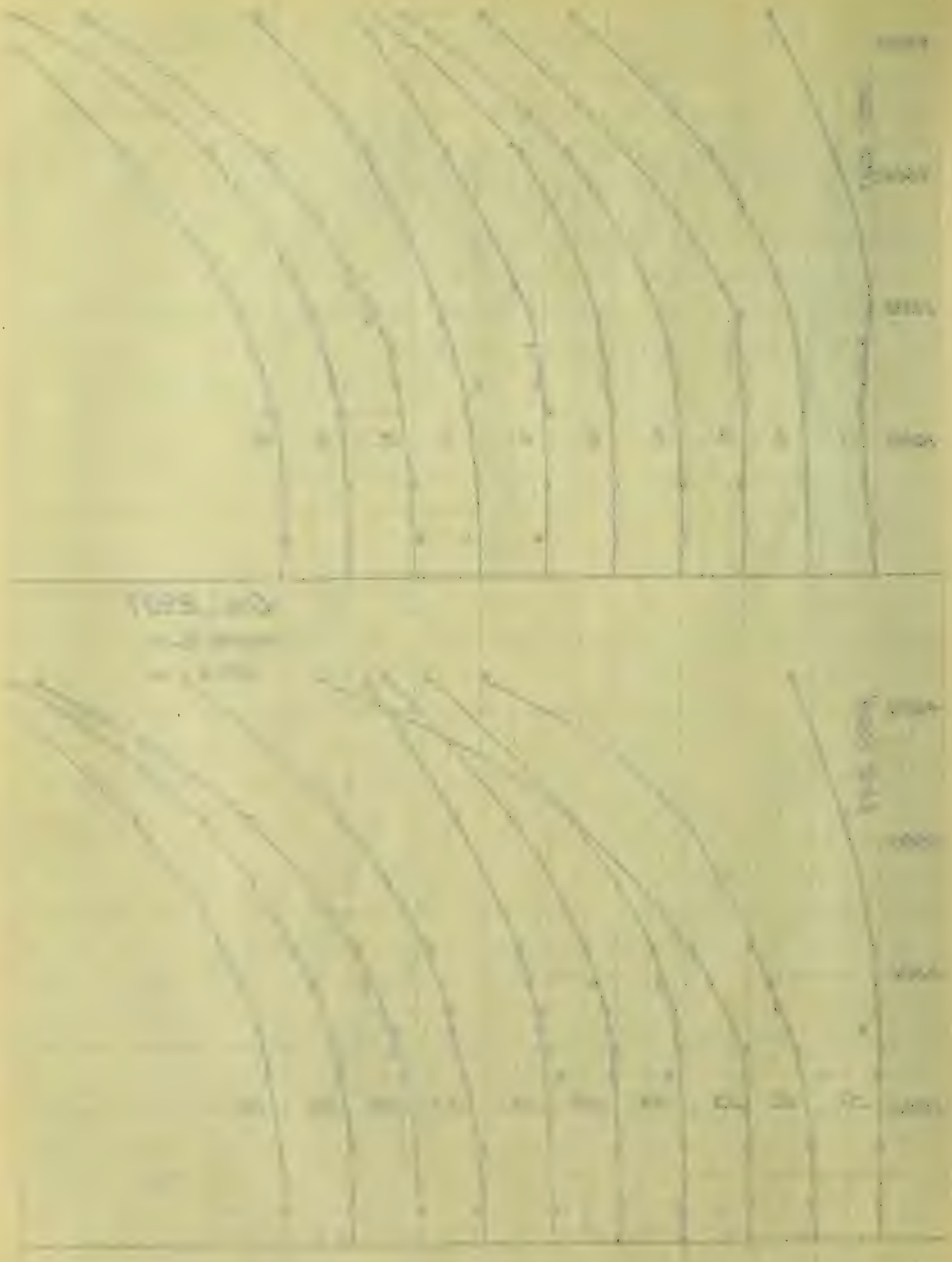


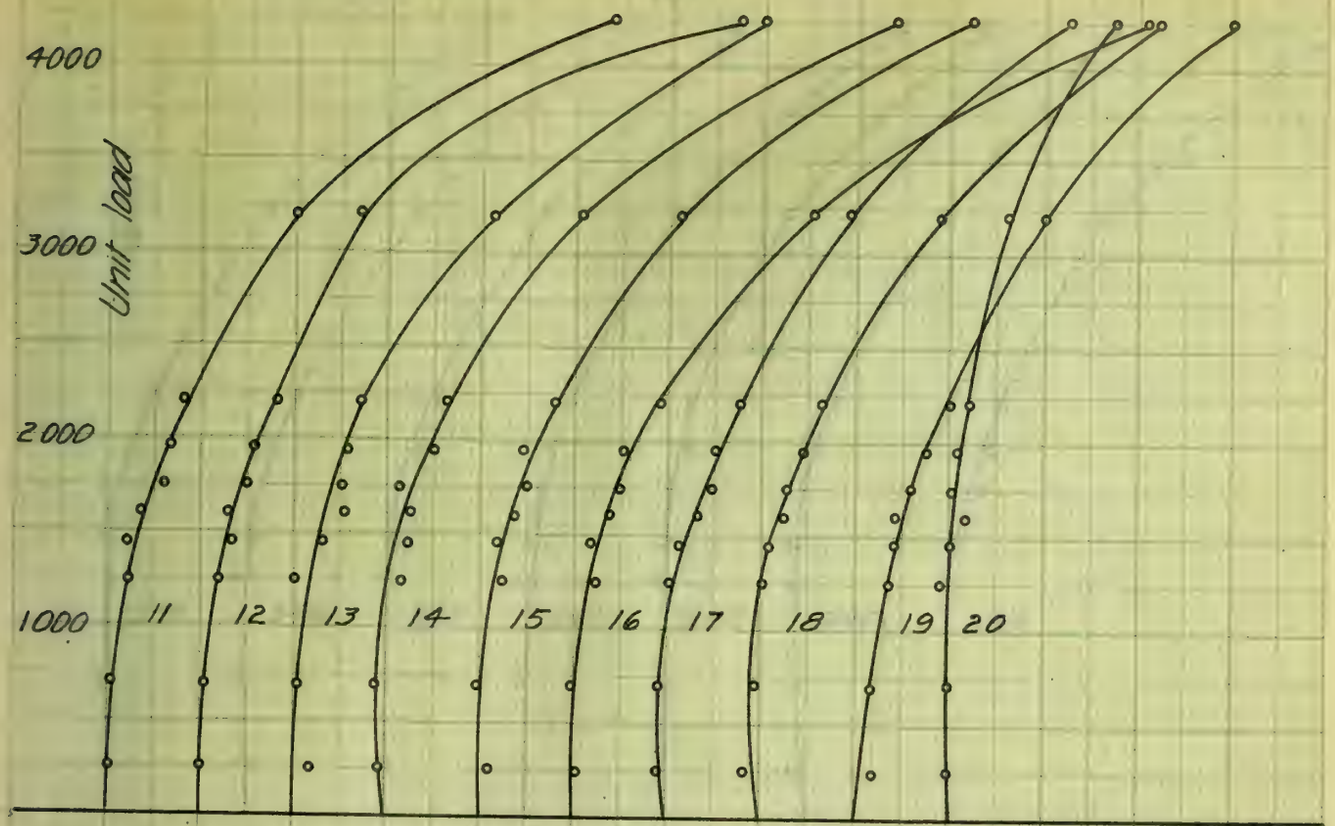


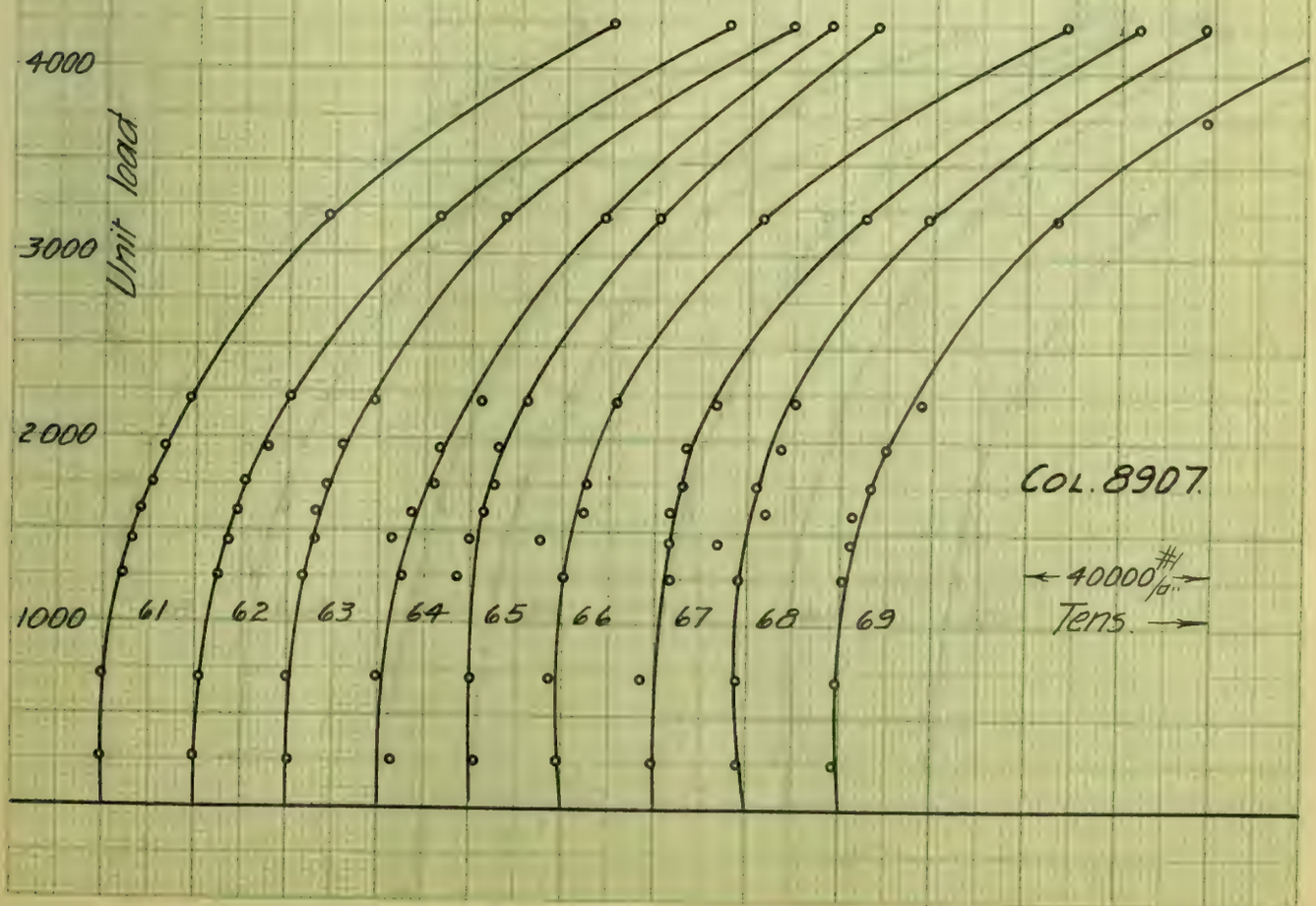

2000
Unit load
1000
101
102
102.
104
105
106
107
108
2000
Unit load
1000
109
110
111
112
113
114
115
116
Col. 8907
.004 in./in.
Comp.

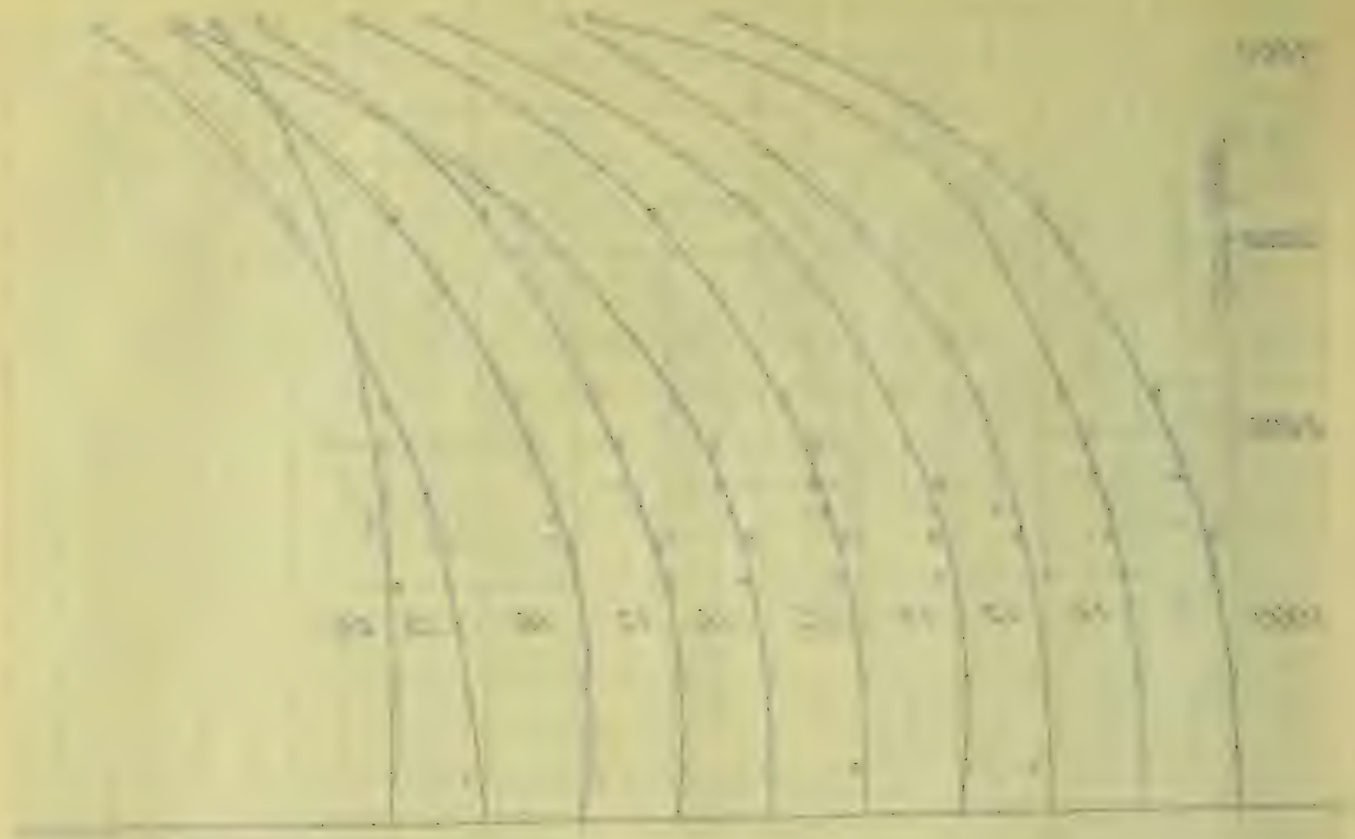


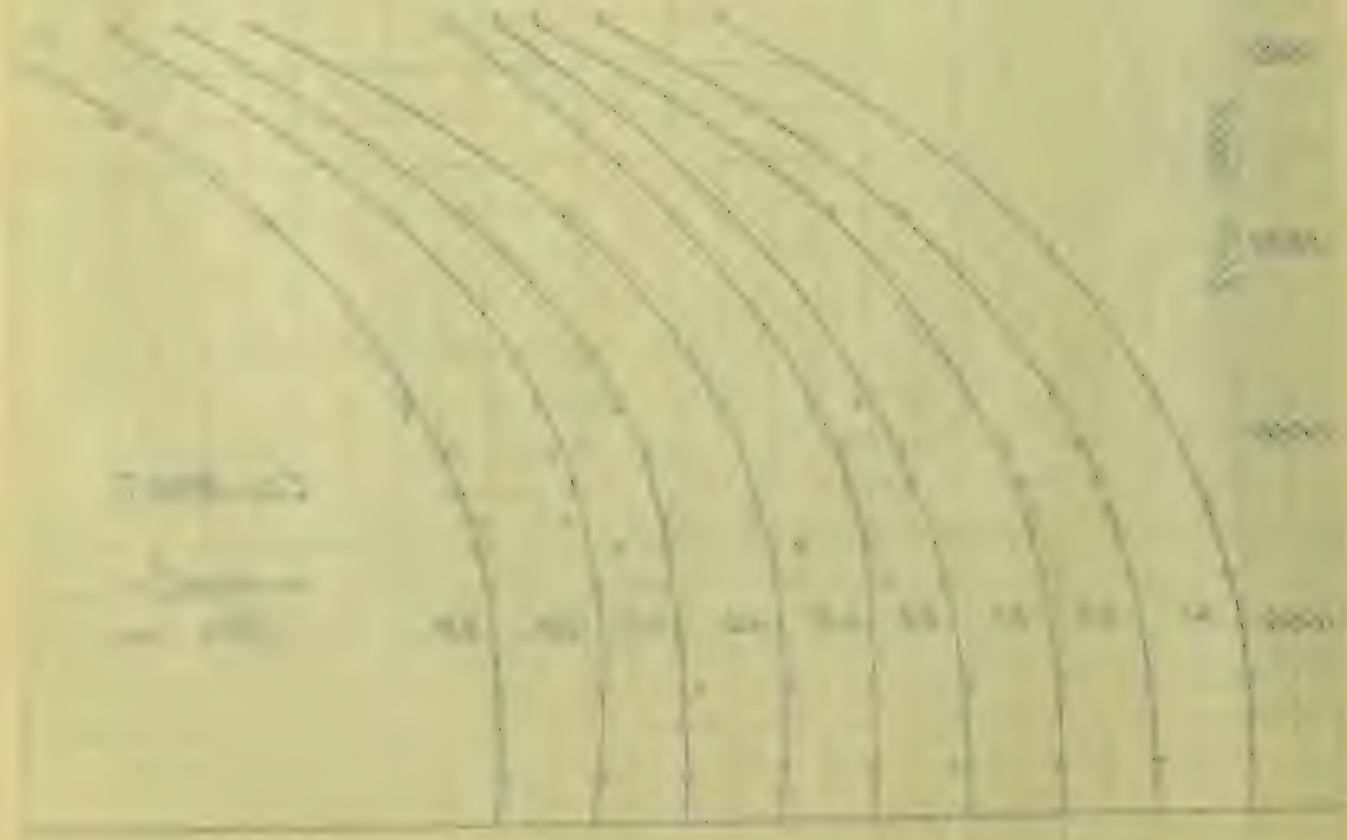

4000
3000
2000
1000
Unit load
1
2
3
4
5
6
7
8
9
10
Col. 8907
←40000 #/in.→
Tens. →
4000
3000
2000
1000
Unit load
51
52
53
54
55
56
57
58
59
60

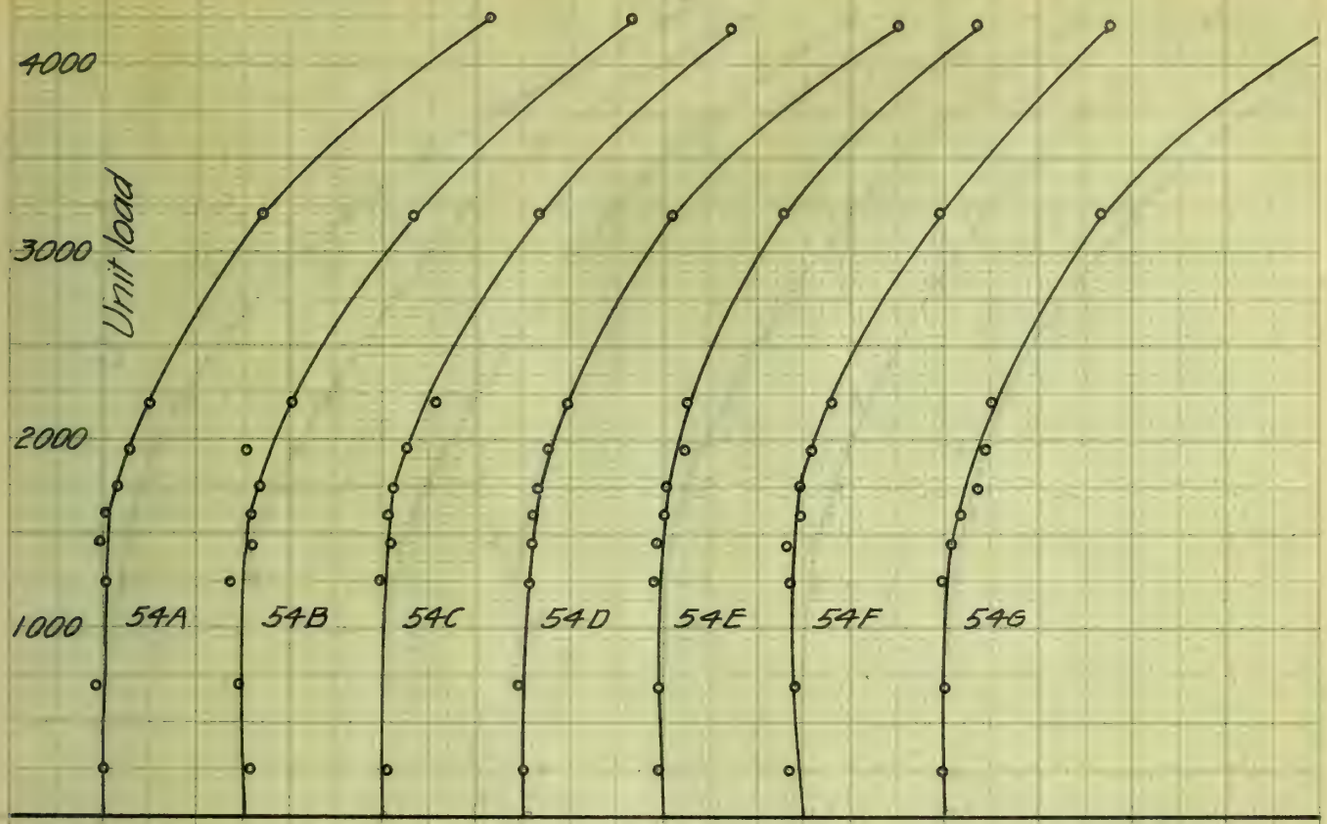



4000
3000
2000
1000
Unit load
11
12
13
14
15
16
17
18
19
20


4000
3000
2000
1000
Unit load
61
62
63
64
65
66
67
68
69
COL. 8907.
40000 #/in.
Tens.

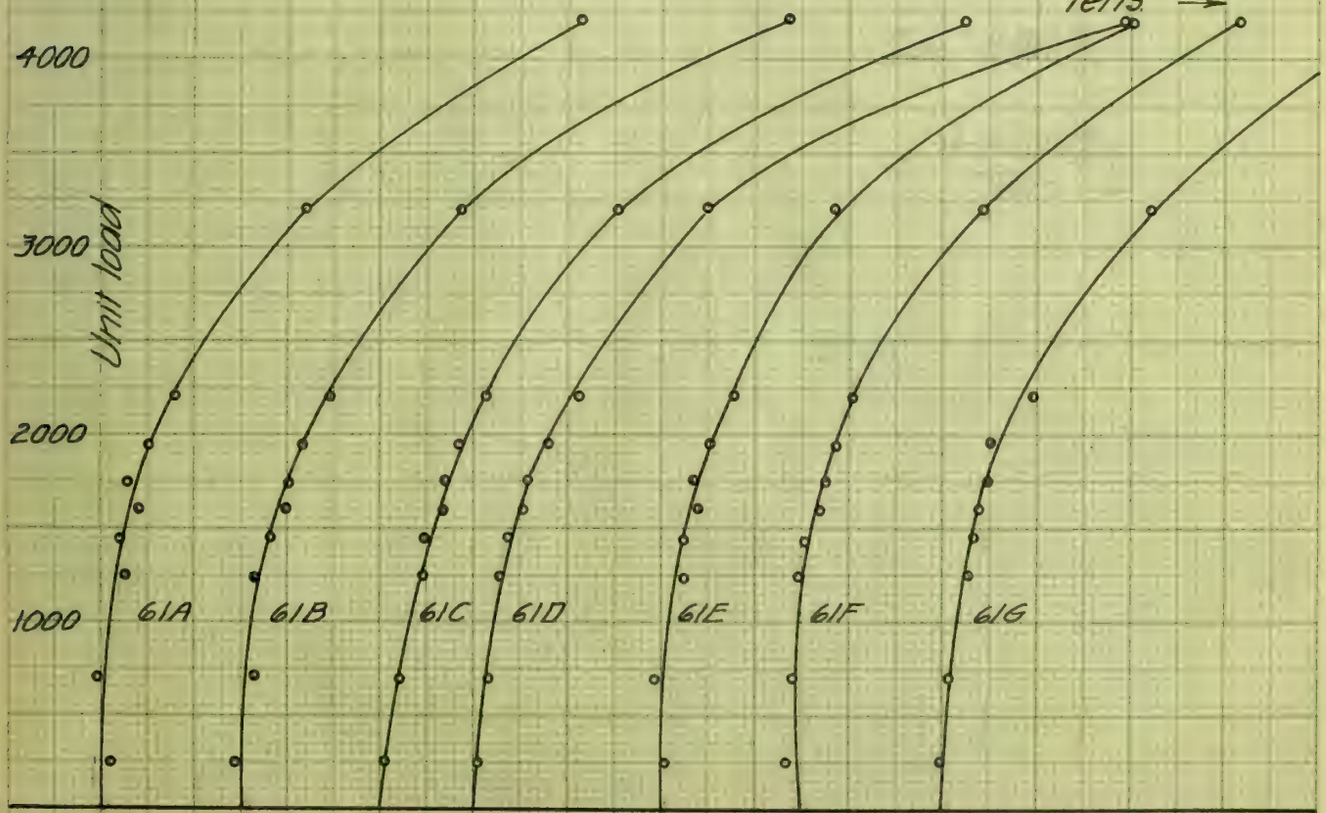






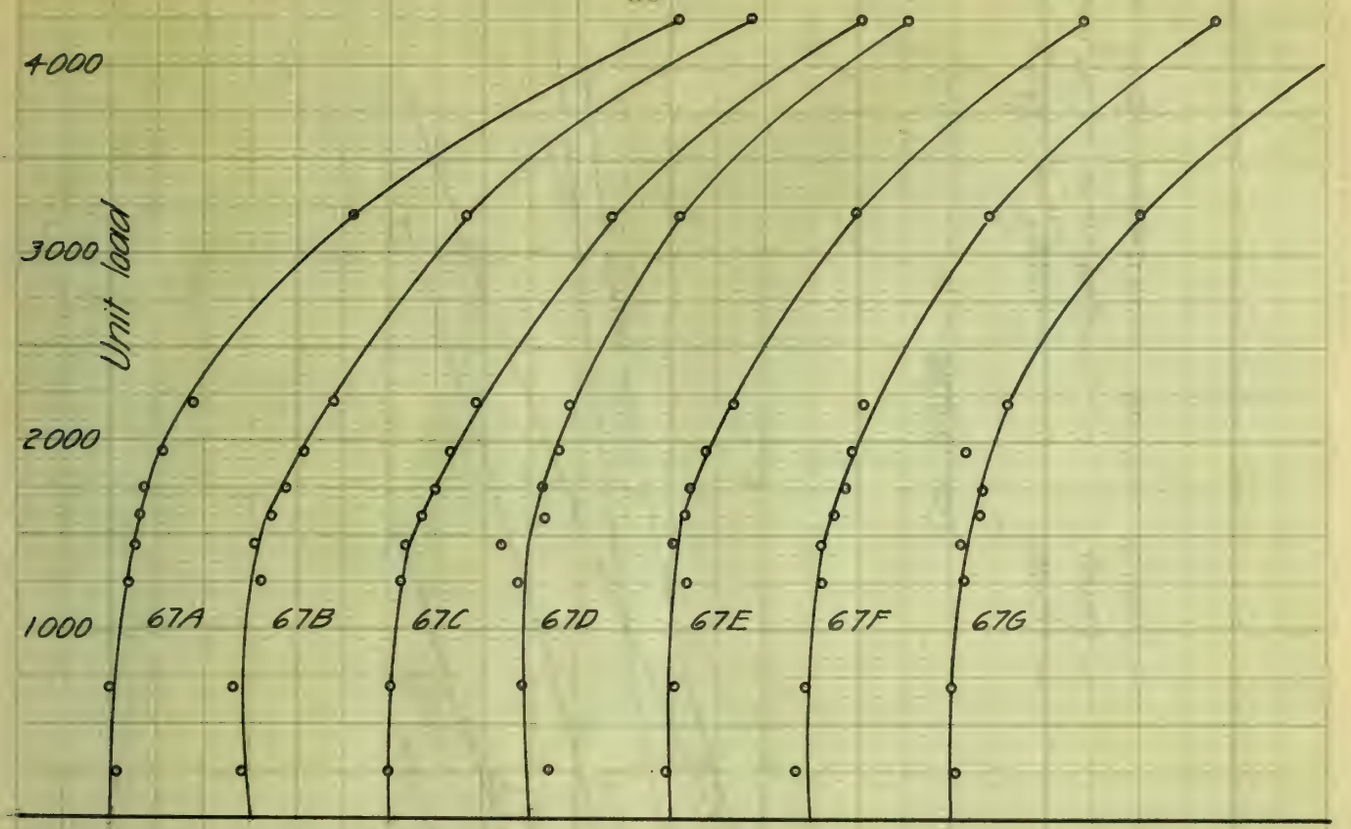
Col. 8907

←40000#/□"→
Tens →





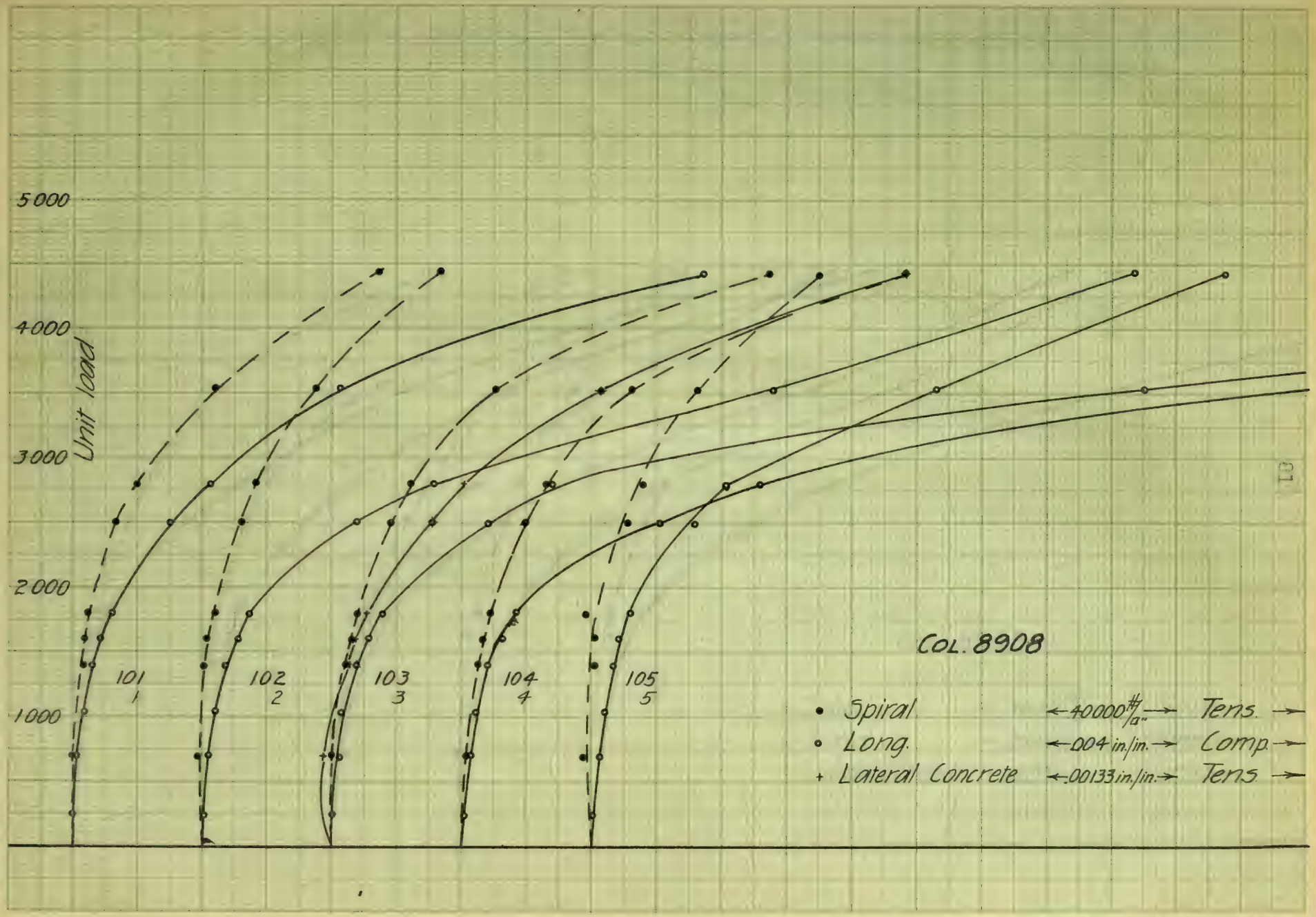


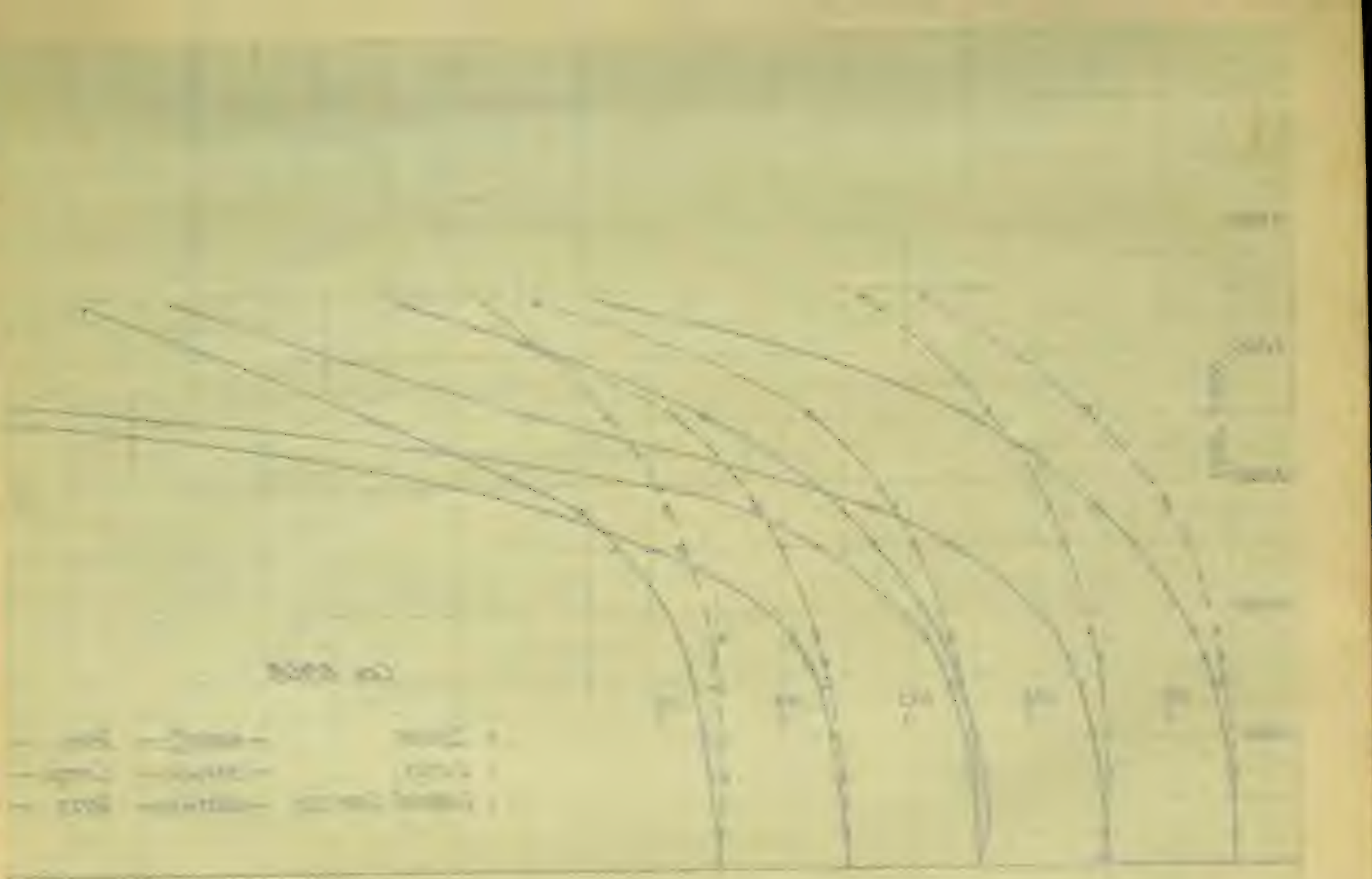


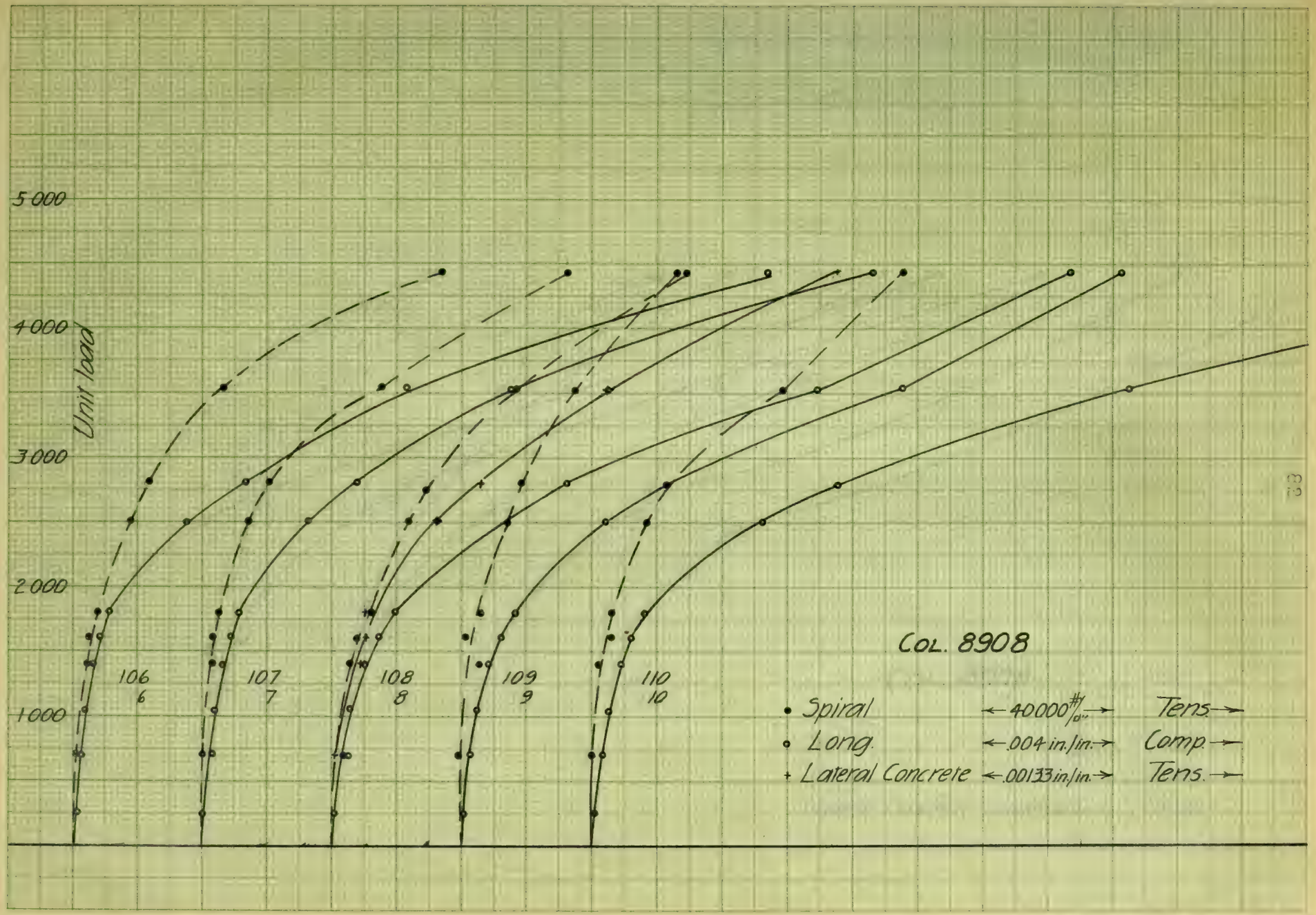
Col. 8907

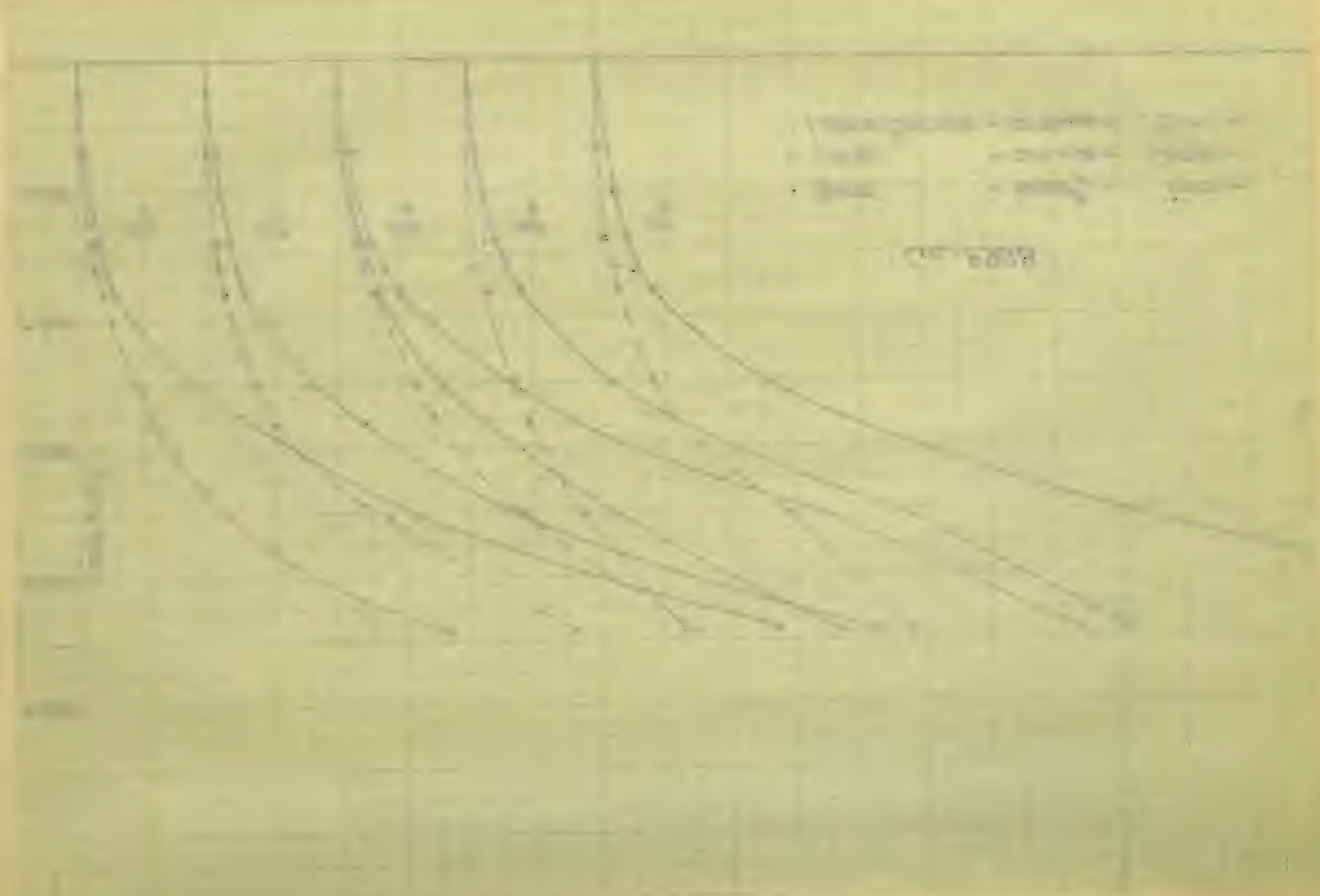
← 40.000 #/in. →
Tens. →

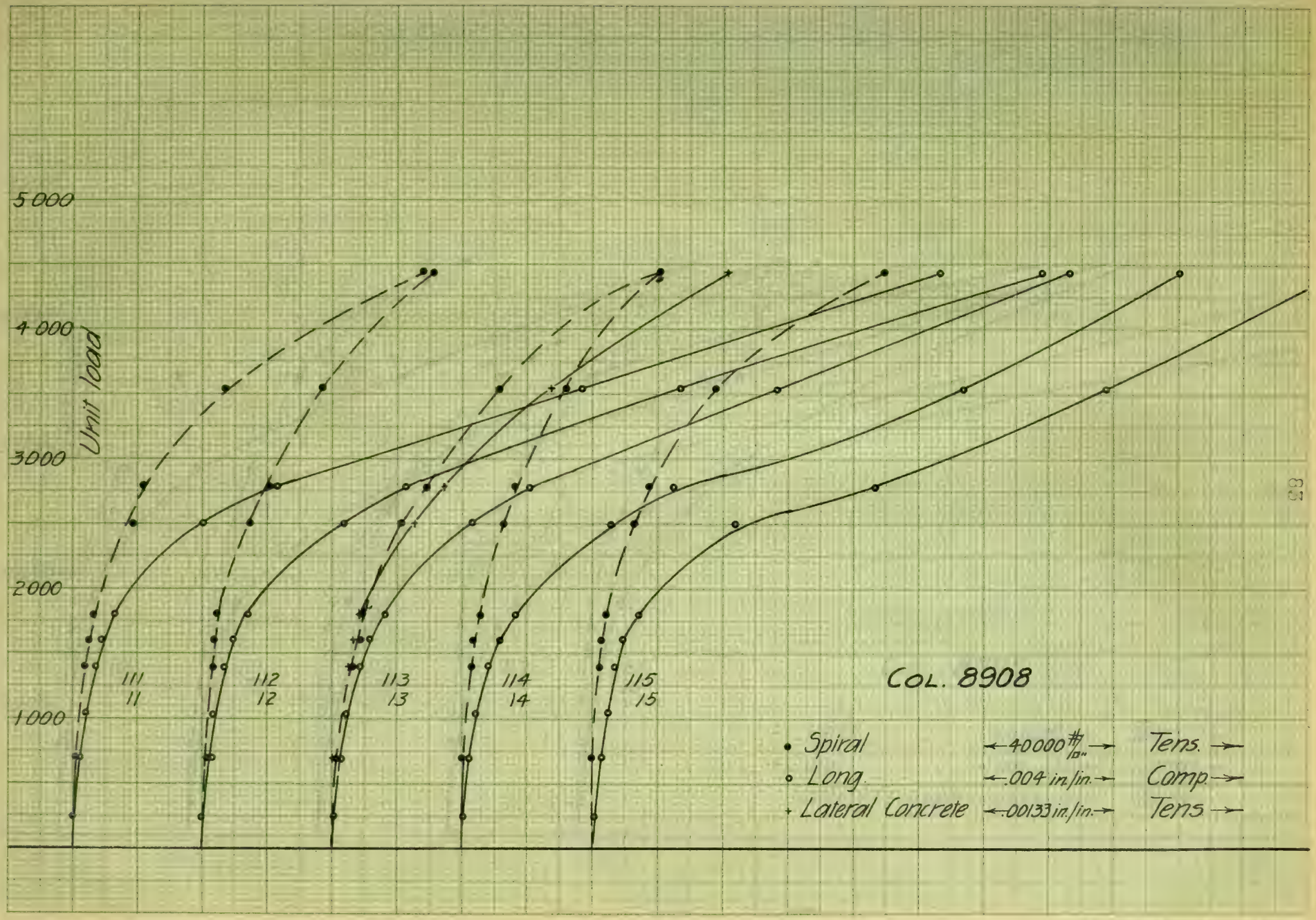


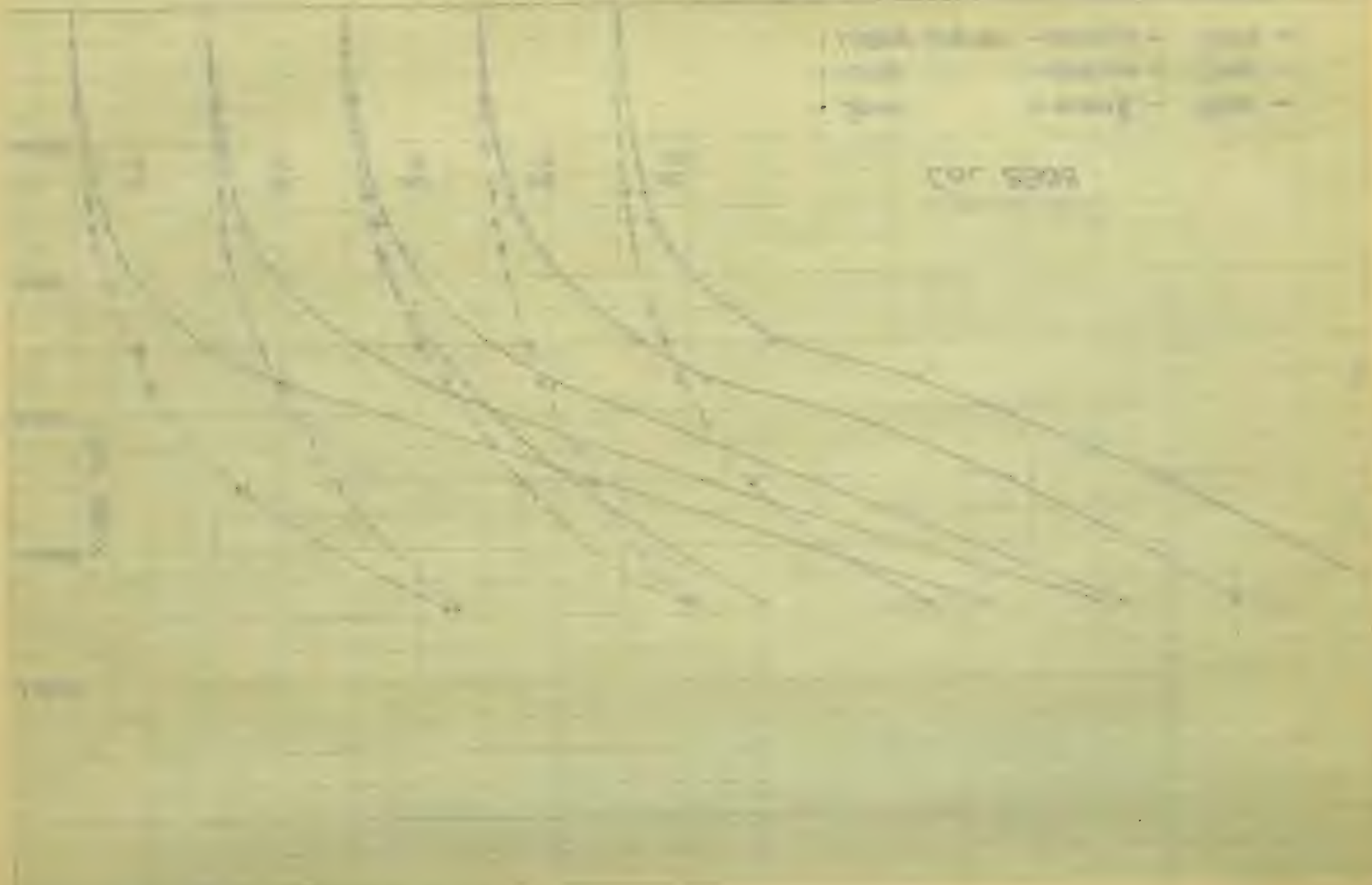

5000
4000
3000
2000
1000
Unit load
101
1
102
2
103
3
104
4
105
5
COL. 8908
• Spiral ←40000#/a"→ Tens.
° Long. ←.004 in./in.→ Comp.
+ Lateral Concrete ←.00133 in./in.→ Tens.

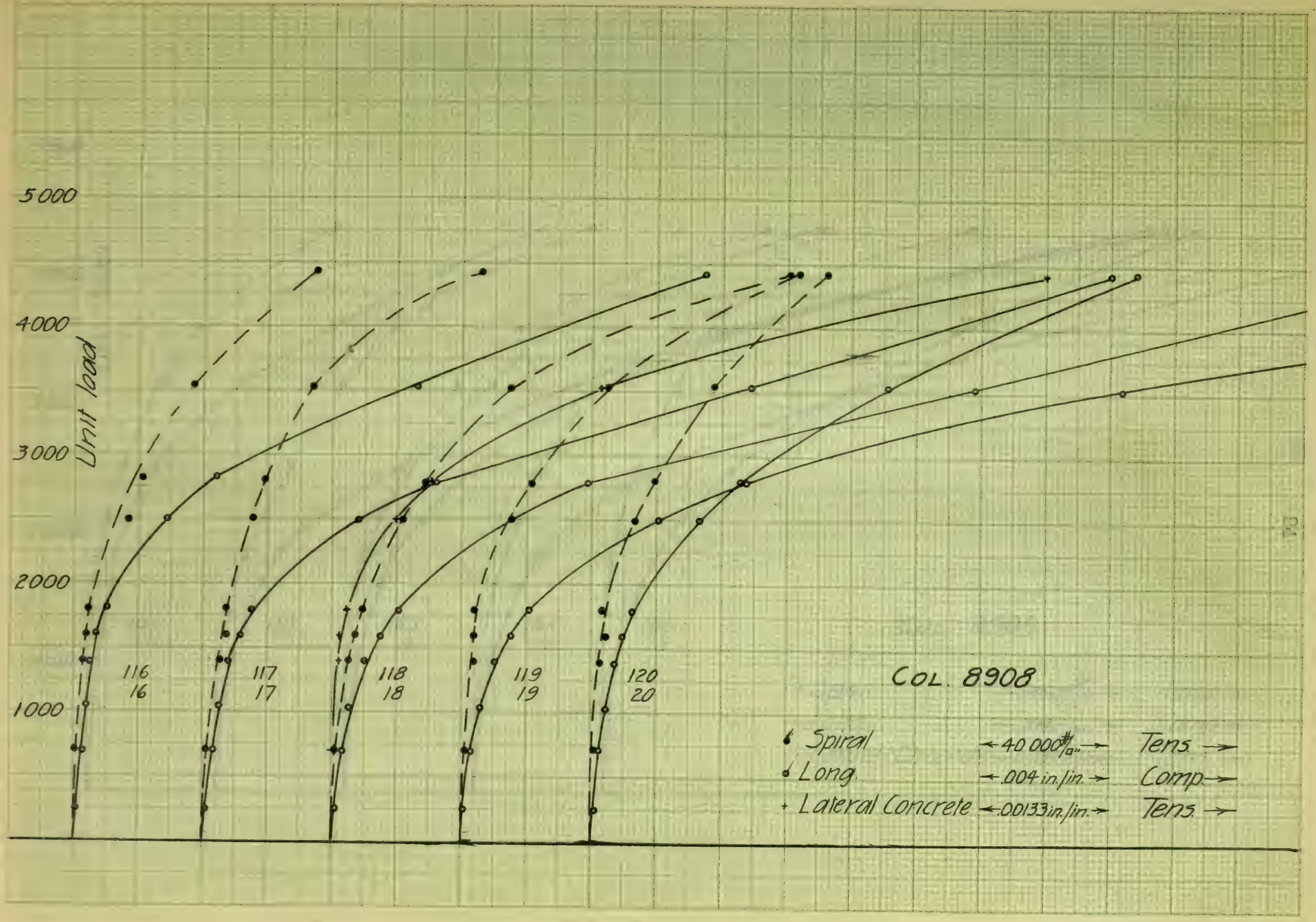


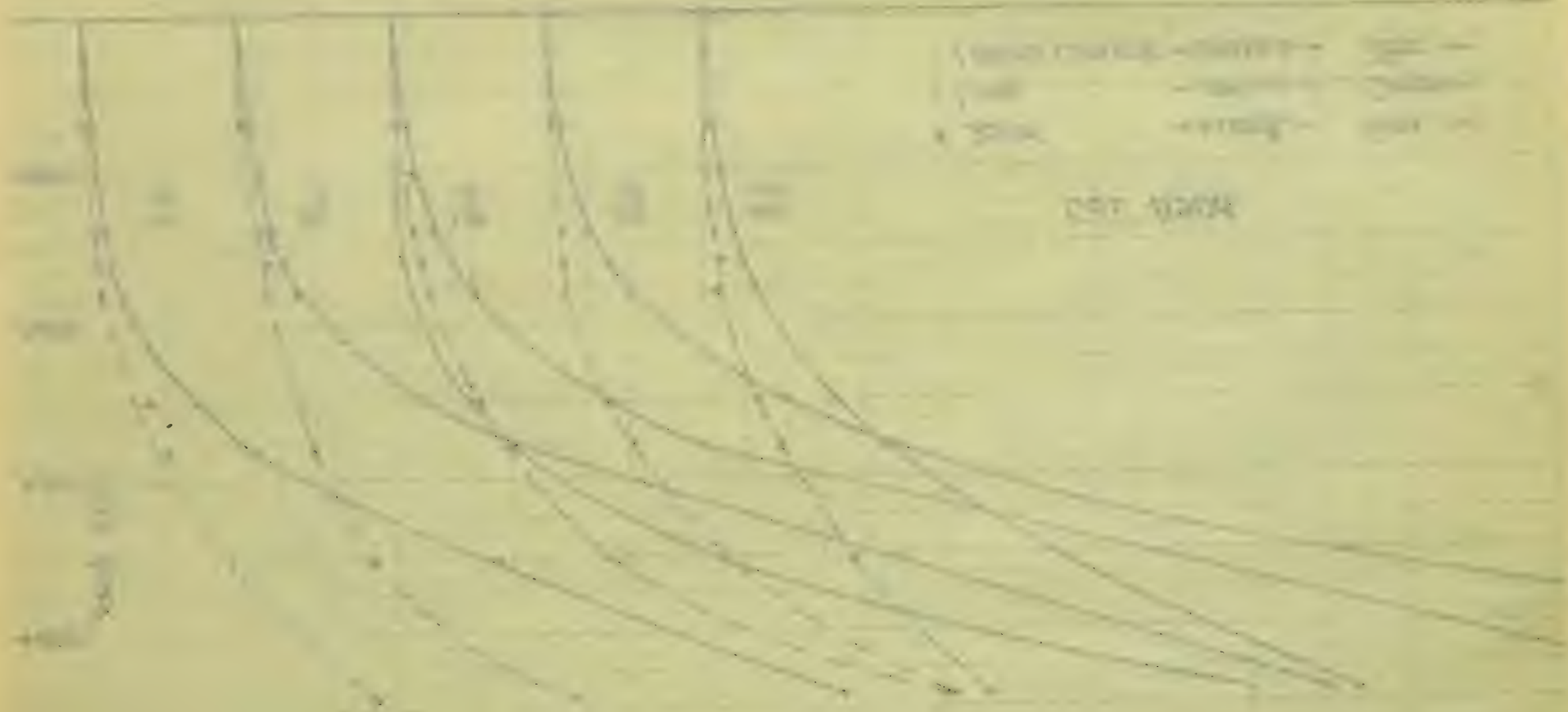

5000
4000
3000
2000
1000
Unit load
106
6
107
7
108
8
109
9
110
10
COL. 8908
• Spiral ← 40000 #/□" → Tens.
○ Long. ← .004 in./in. → Comp.
+ Lateral Concrete ← .00133 in./in. → Tens.

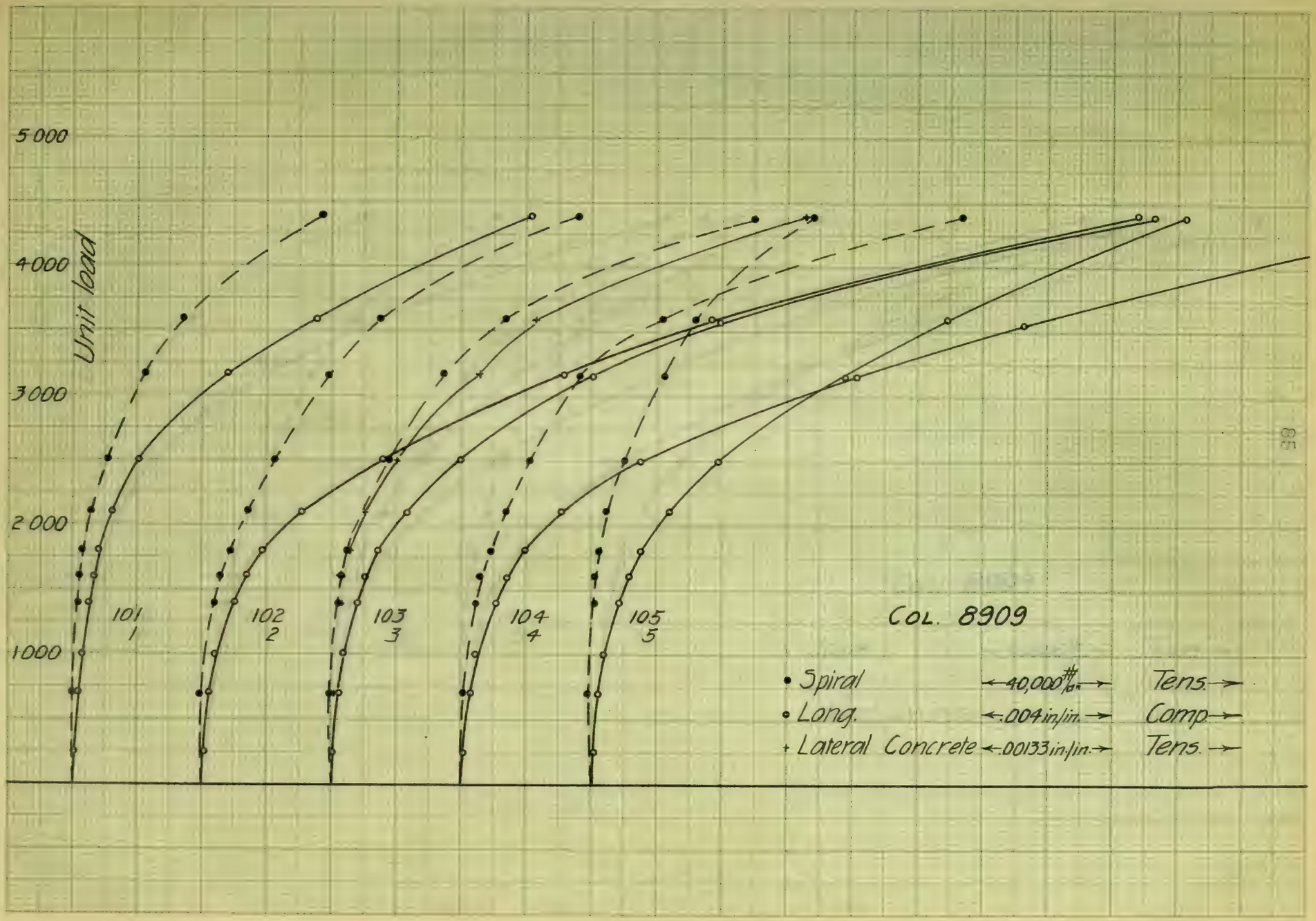



5000
4000
3000
2000
1000
Unit load
111
11
112
12
113
13
114
14
115
15
COL. 8908
Spiral ←40000 #/in.→ Tens. →
Long. ←.004 in./in.→ Comp. →
Lateral Concrete ←.00133 in./in.→ Tens →

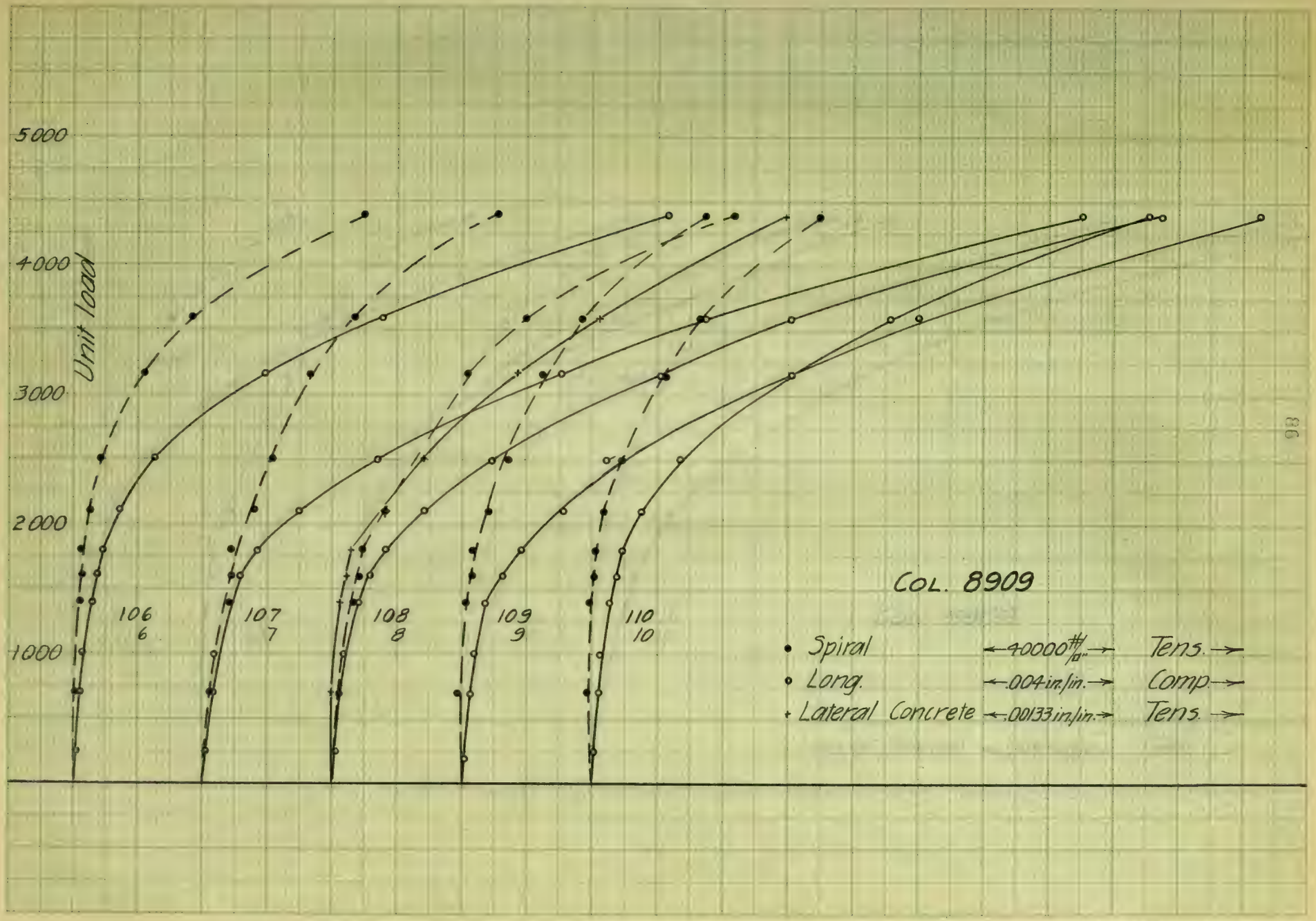



5000
4000
3000
2000
1000
Unit load
116
16
117
17
118
18
119
19
120
20
COL. 8908
Spiral ←40 000#/□"→ Tens.→
Long. ←.004 in./in.→ Comp.→
Lateral Concrete ←.00133 in./in.→ Tens.→

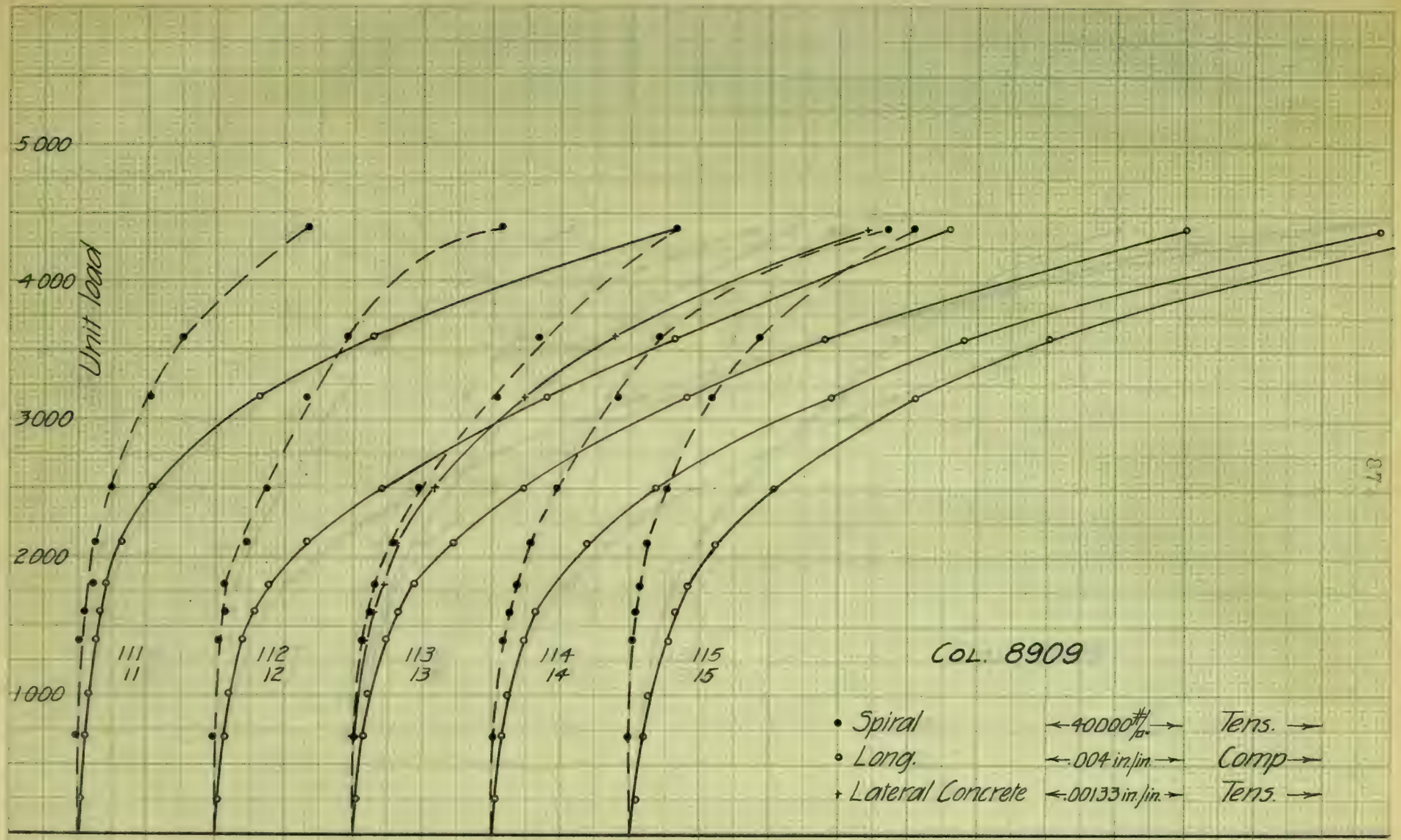



5000
4000
3000
2000
1000
Unit load
101
1
102
2
103
3
104
4
105
5
COL. 8909
• Spiral ←40,000#/in.→ Tens.→
∘ Long. ←.004 in/in.→ Comp.→
+ Lateral Concrete ←.00133 in/in.→ Tens.→

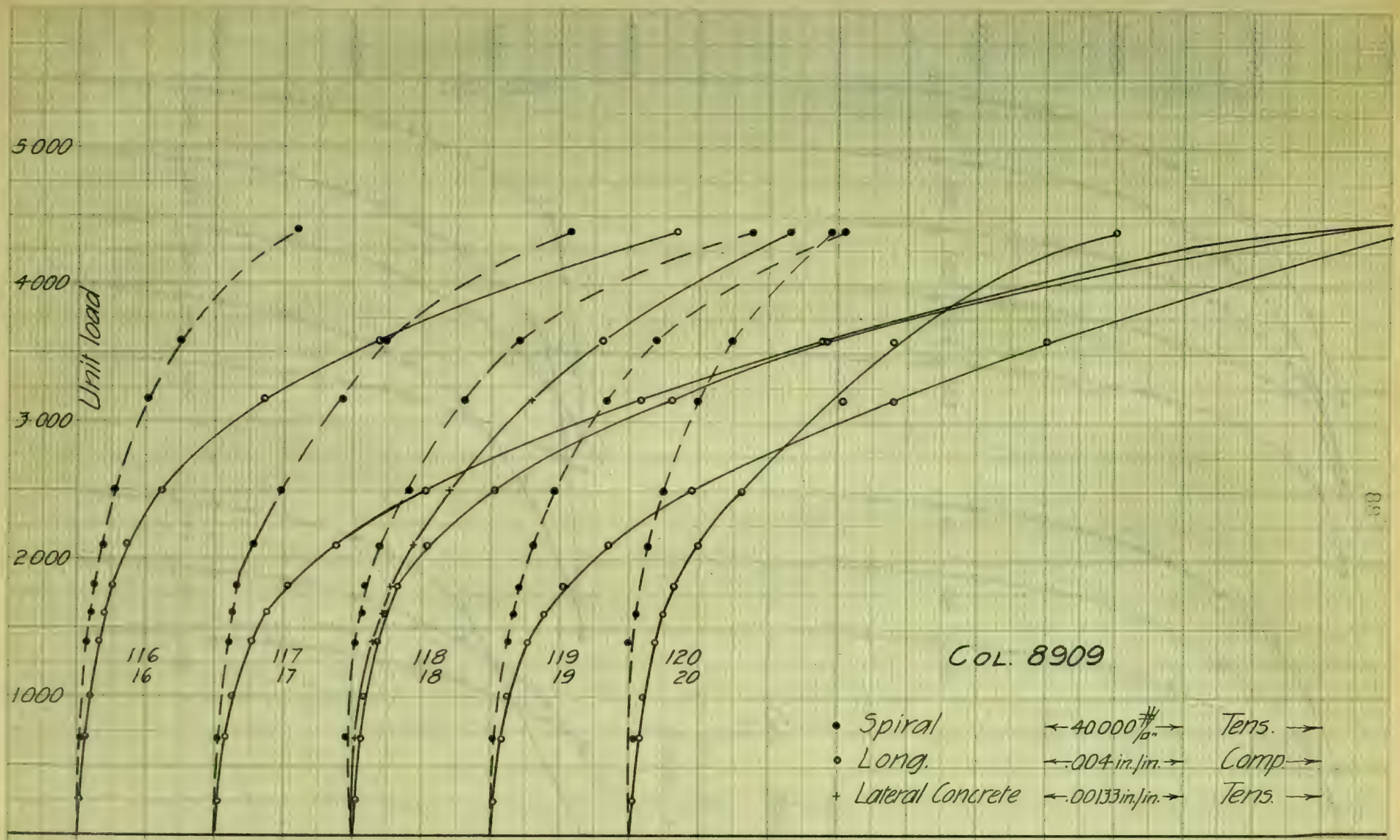


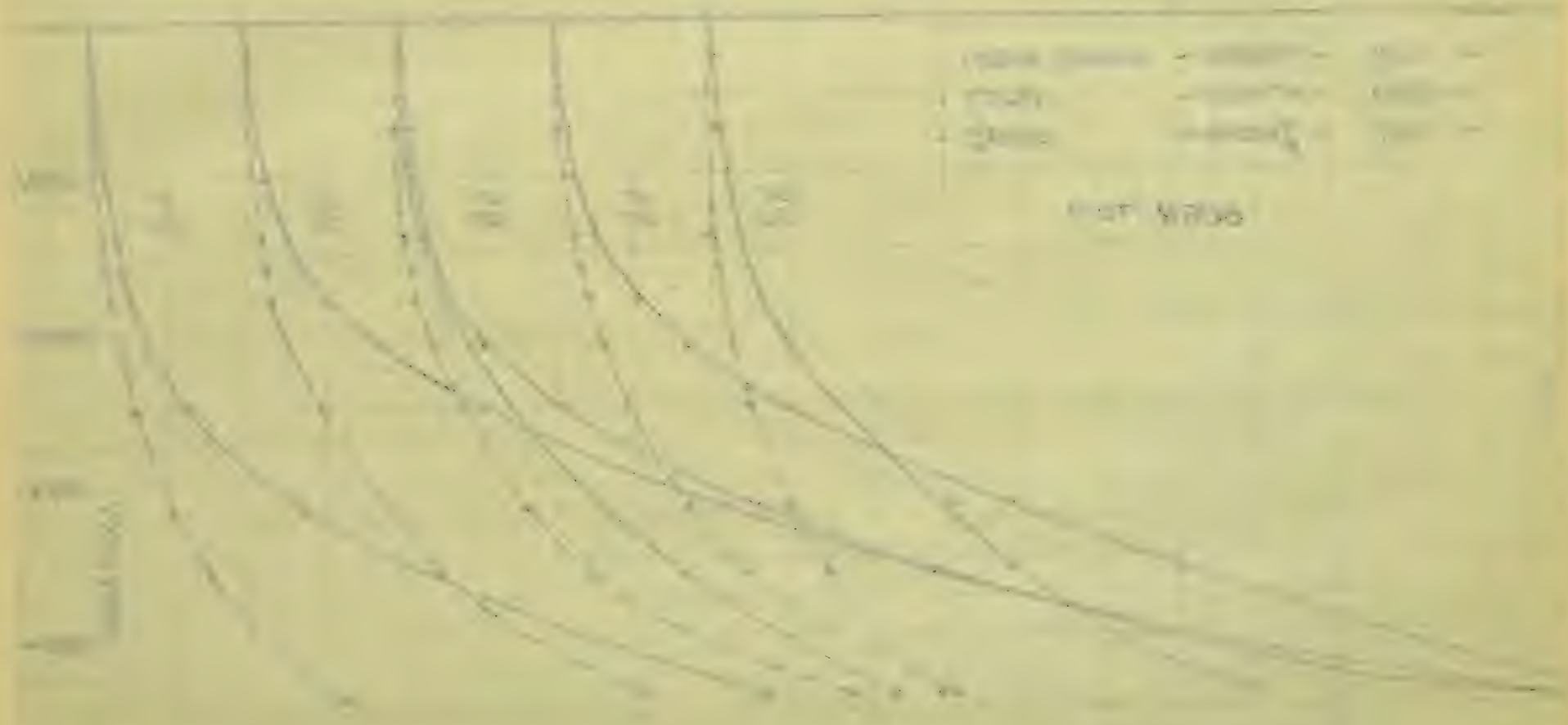

5000
4000
3000
2000
1000
Unit load
106
6
107
7
108
8
109
9
110
10
COL. 8909
• Spiral ←40000#/in.→ Tens.→
○ Long. ←.004 in./in.→ Comp.→
+ Lateral Concrete ←.00133 in./in.→ Tens.→

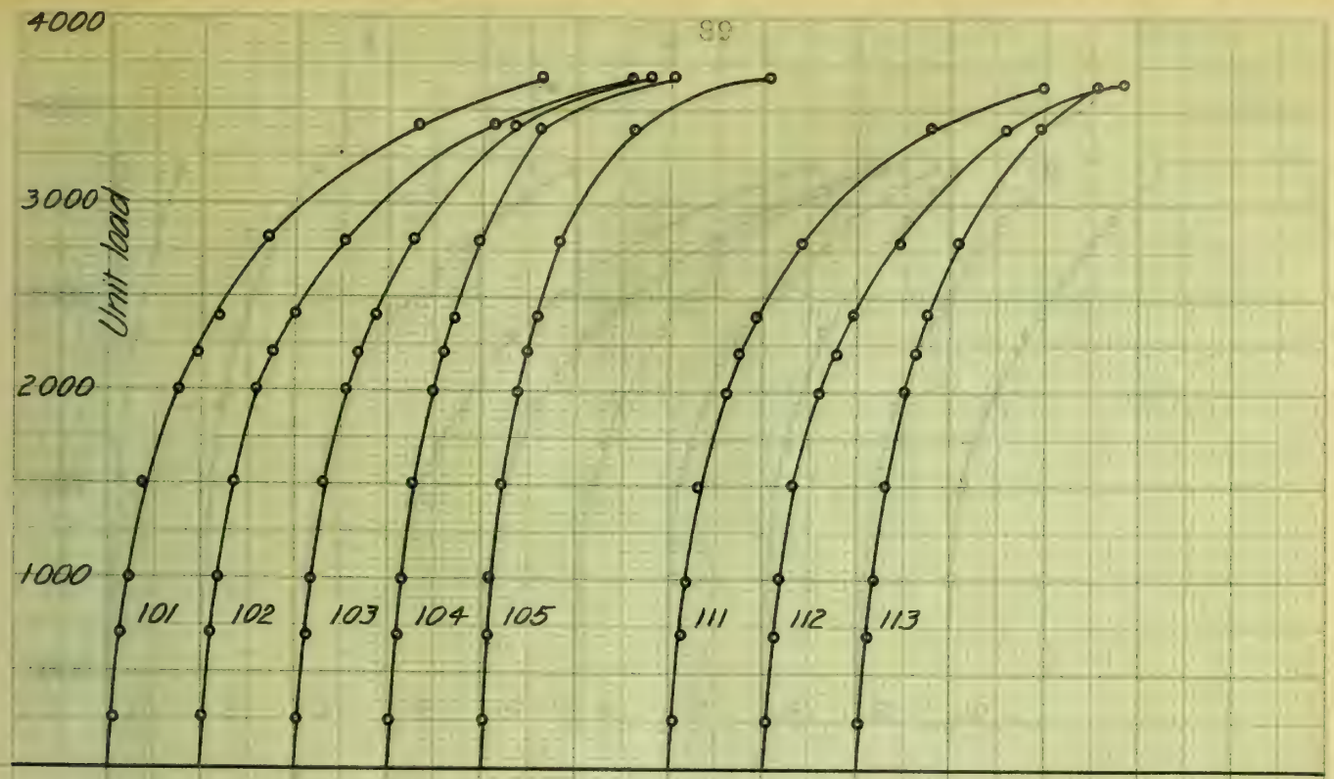



5000
4000
3000
2000
1000
Unit load
111
11
112
12
113
13
114
14
115
15
COL. 8909
• Spiral ←40000#/in.→ Tens. →
∘ Long. ←.004 in./in.→ Comp →
+ Lateral Concrete ←.00133 in./in.→ Tens. →



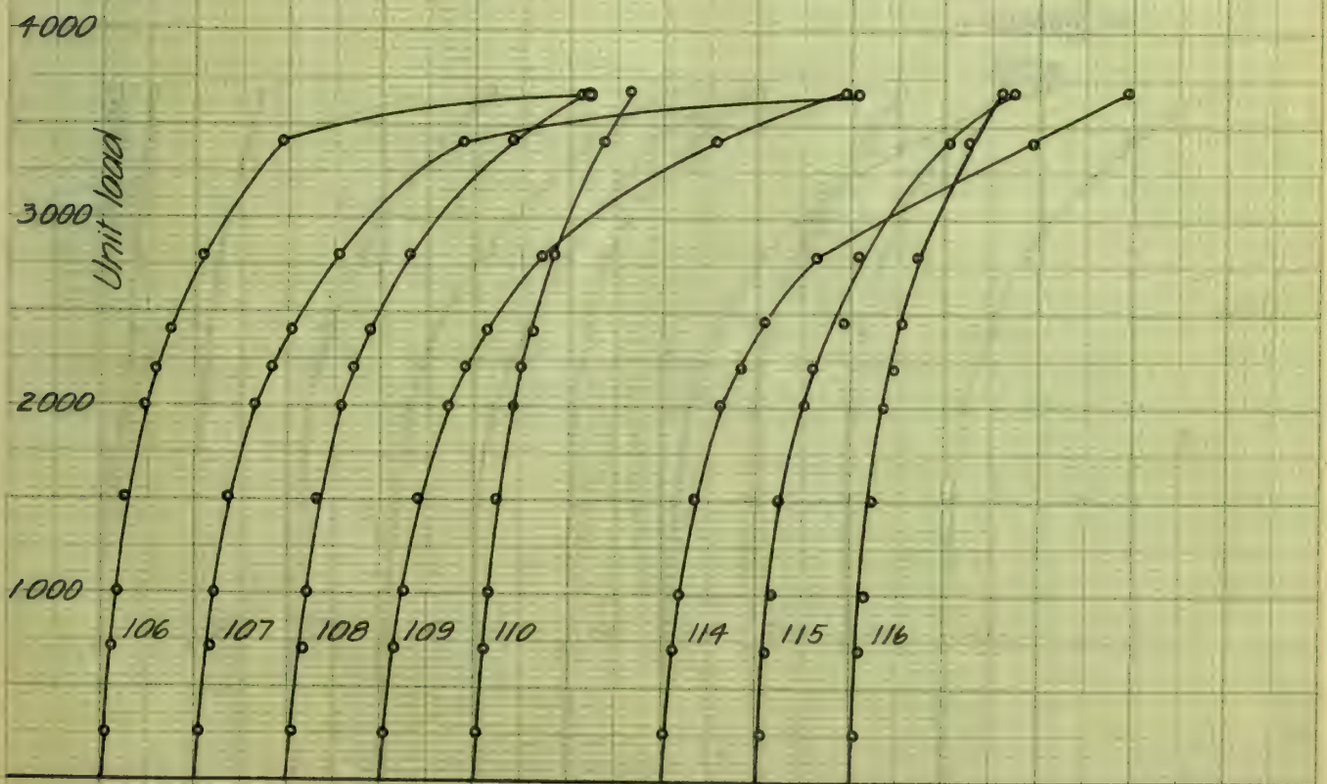

5000
4000
3000
2000
1000
Unit load
116
16
117
17
118
18
119
19
120
20
COL. 8909
• Spiral ←40000 #/in.→ Tens. →
○ Long. ←.004 in./in.→ Comp. →
+ Lateral Concrete ←.00133 in./in.→ Tens. →

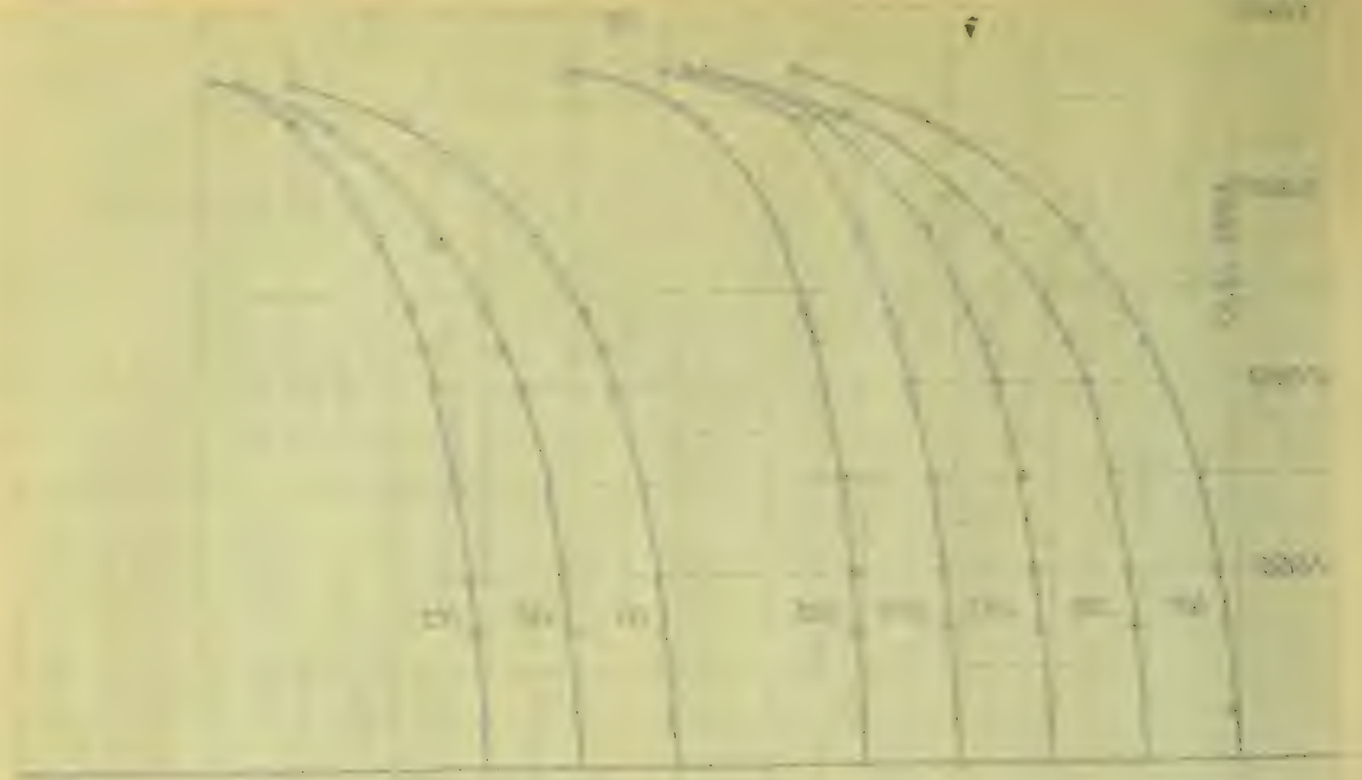


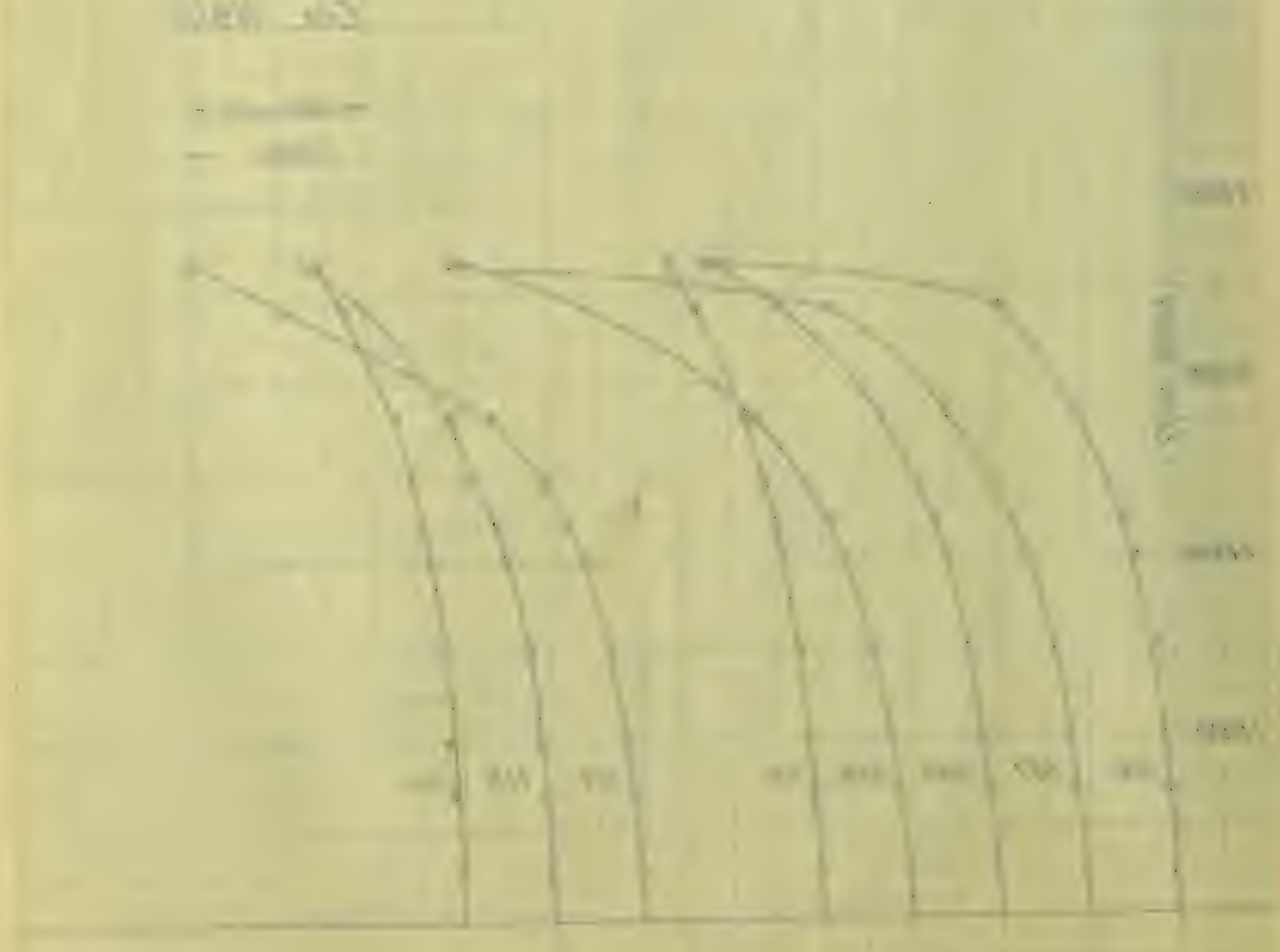


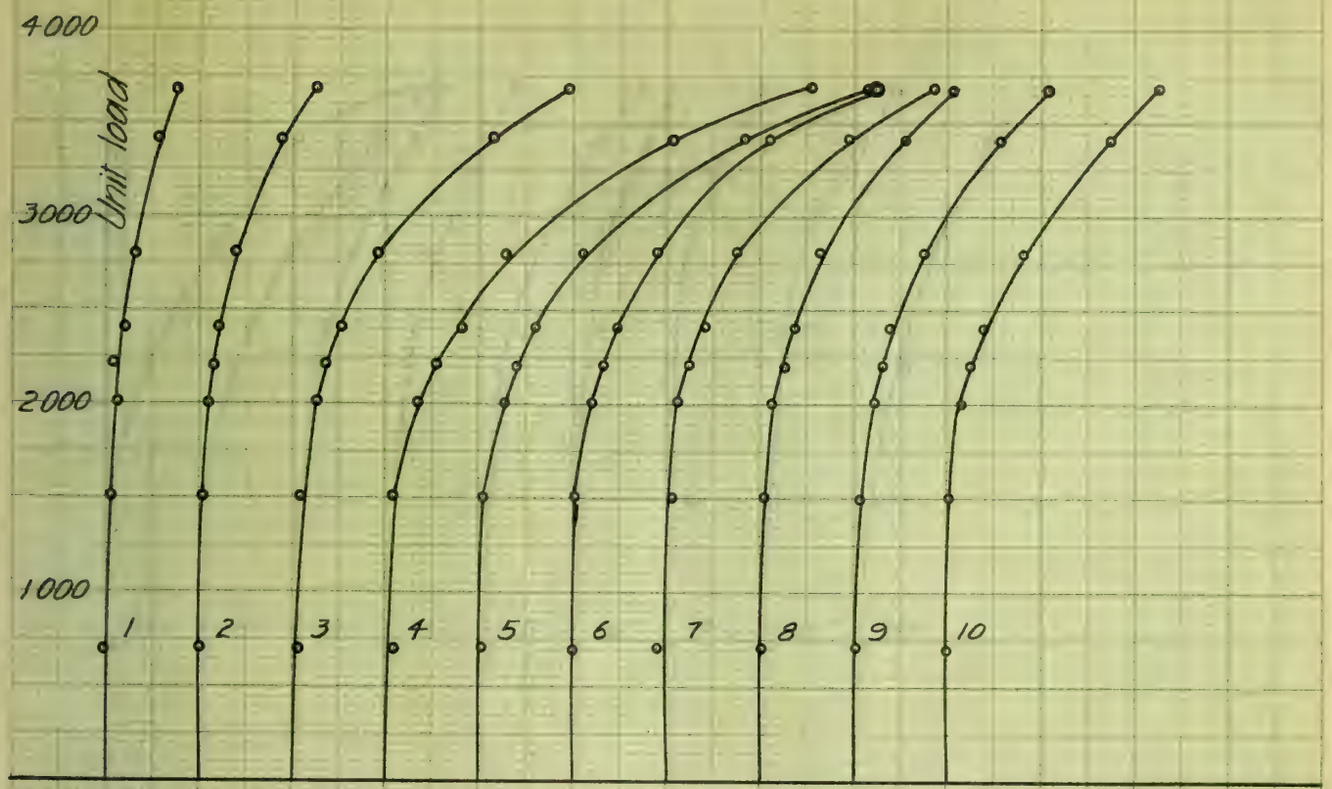
COL. 8910

←.004 in./in.→
Comp. →

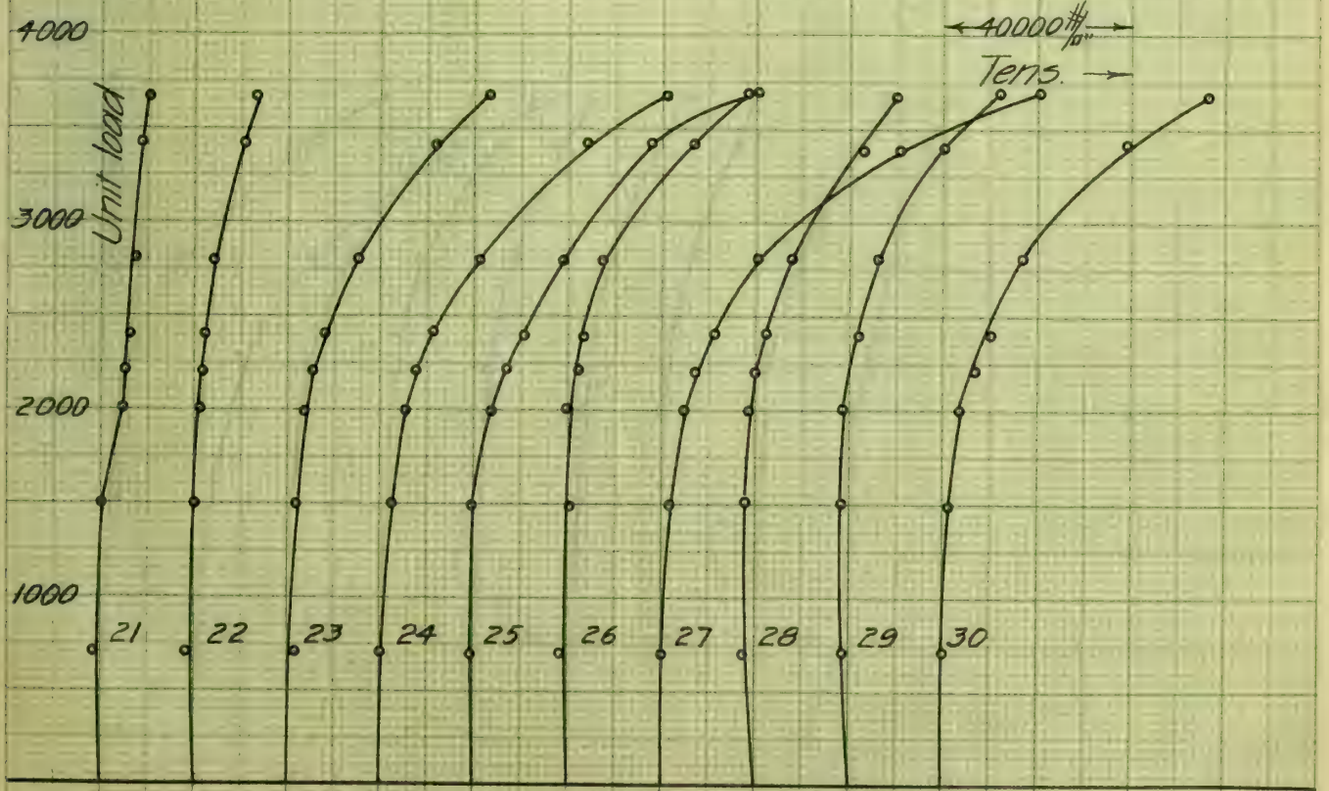


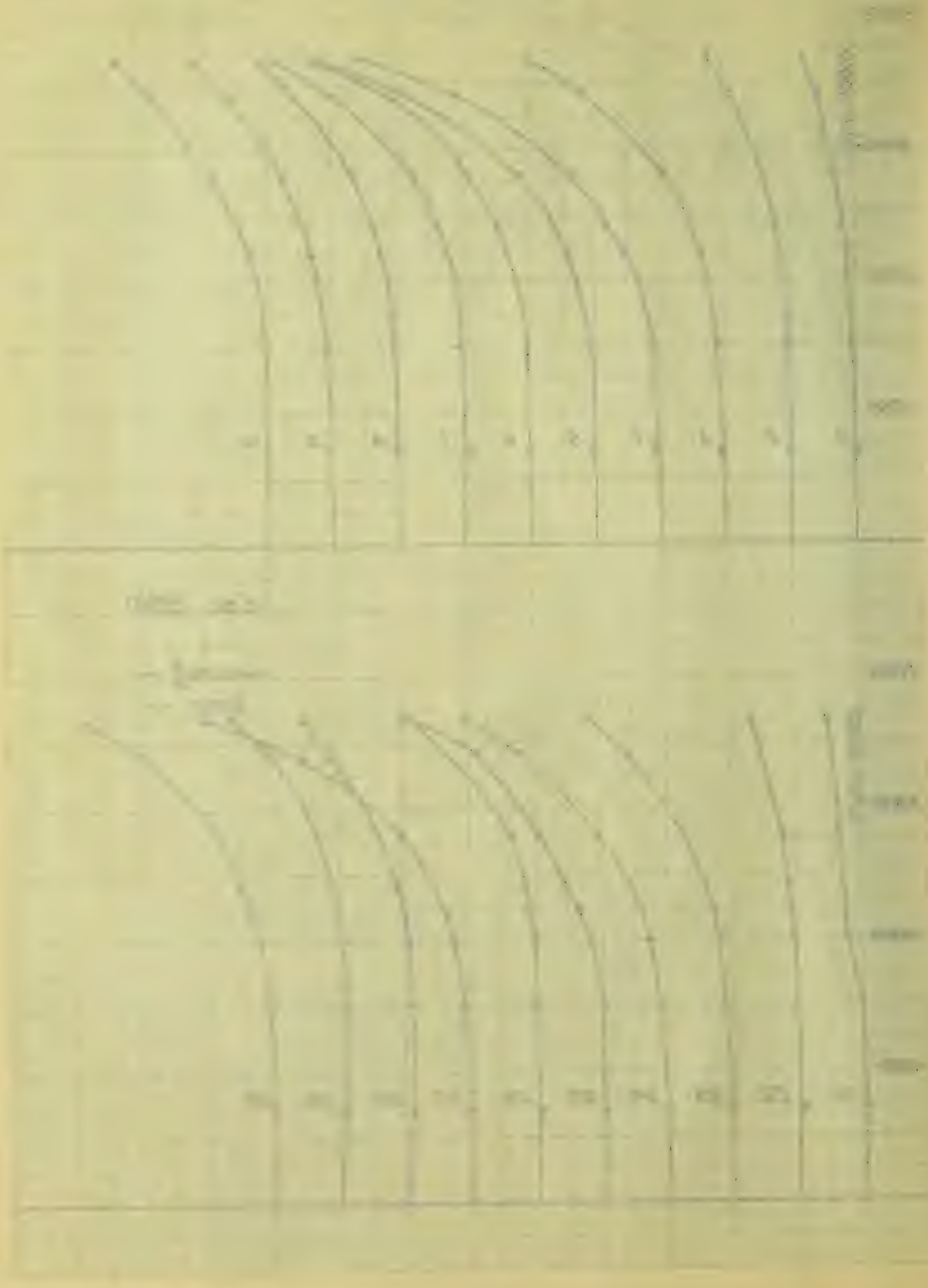


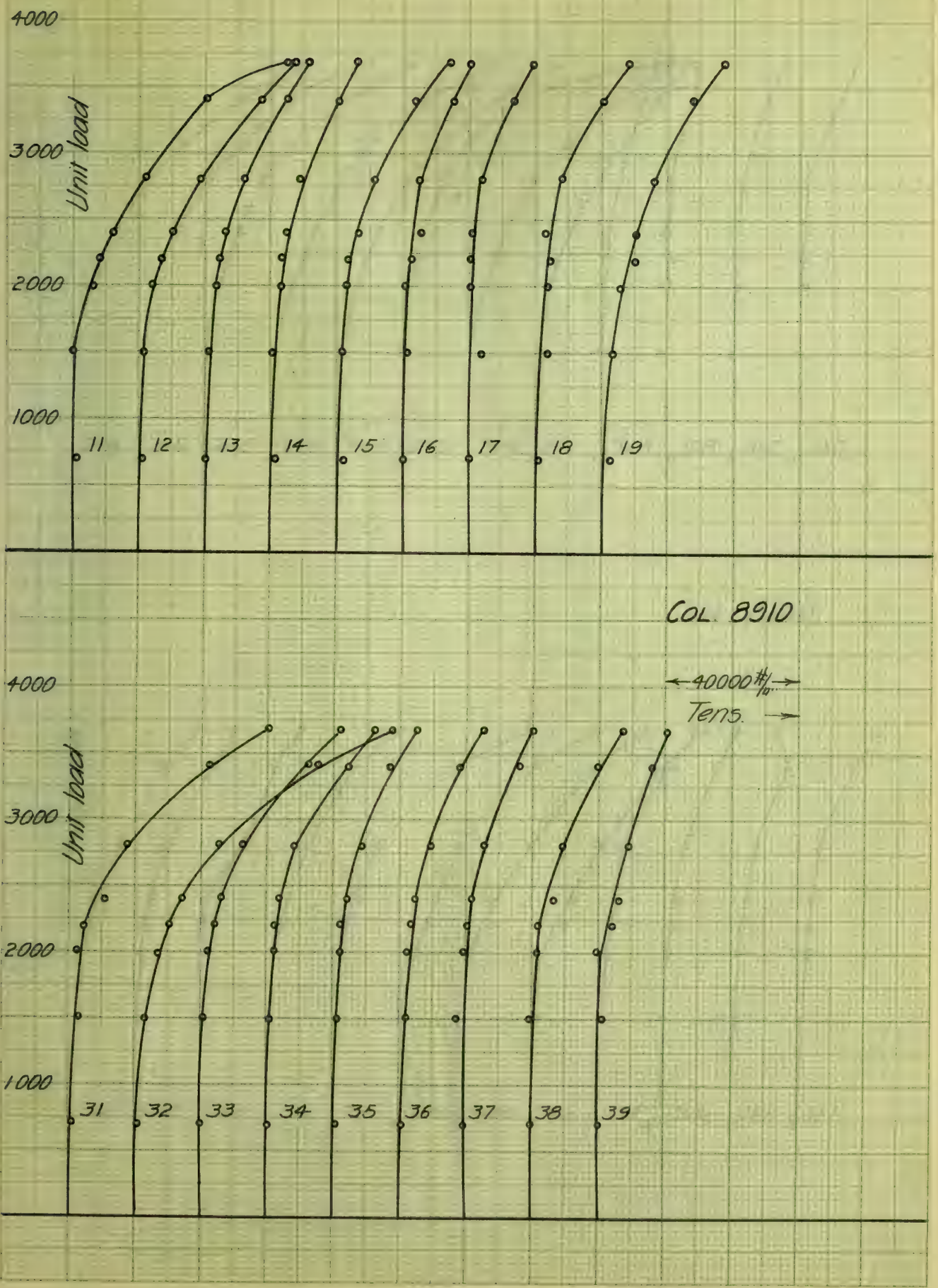


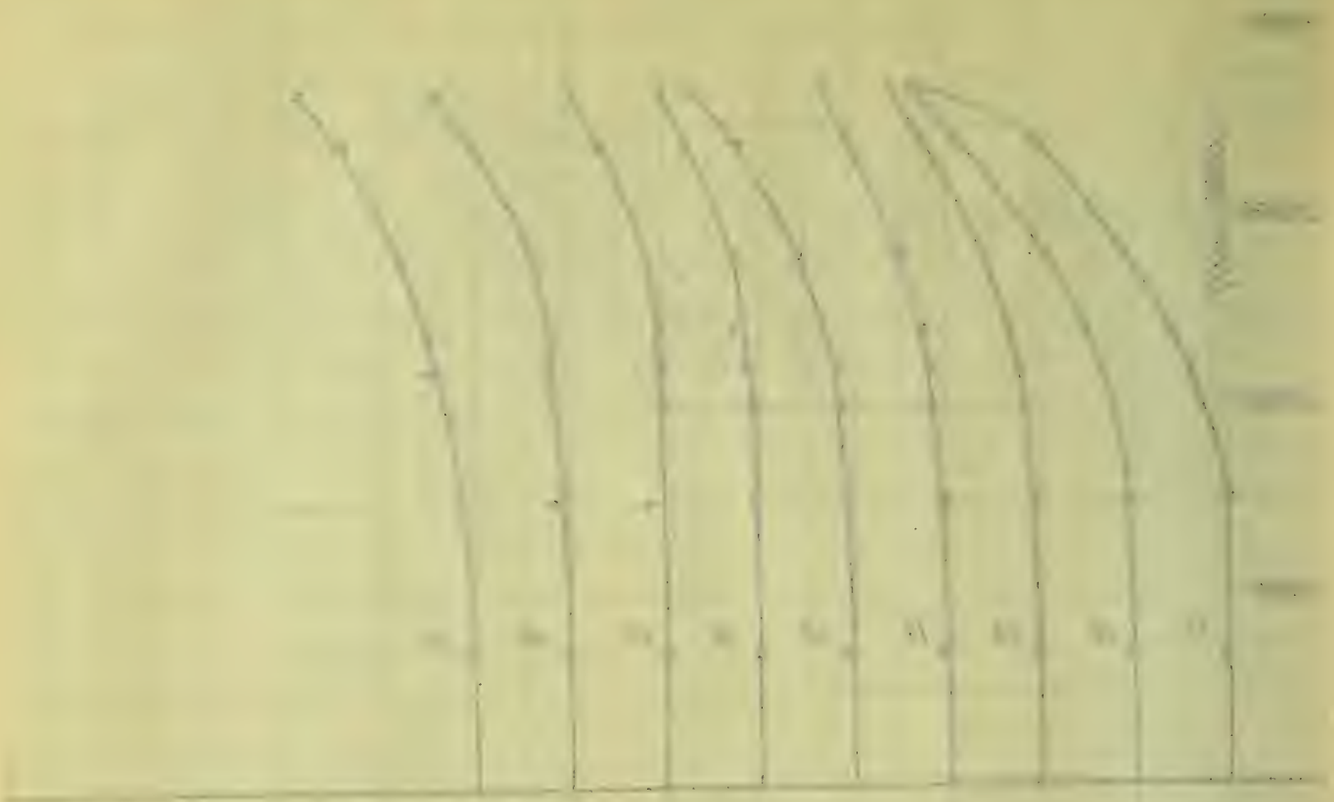

4000
3000
2000
1000
Unit load
1
2
3
4
5
6
7
8
9
10

COL. 8910

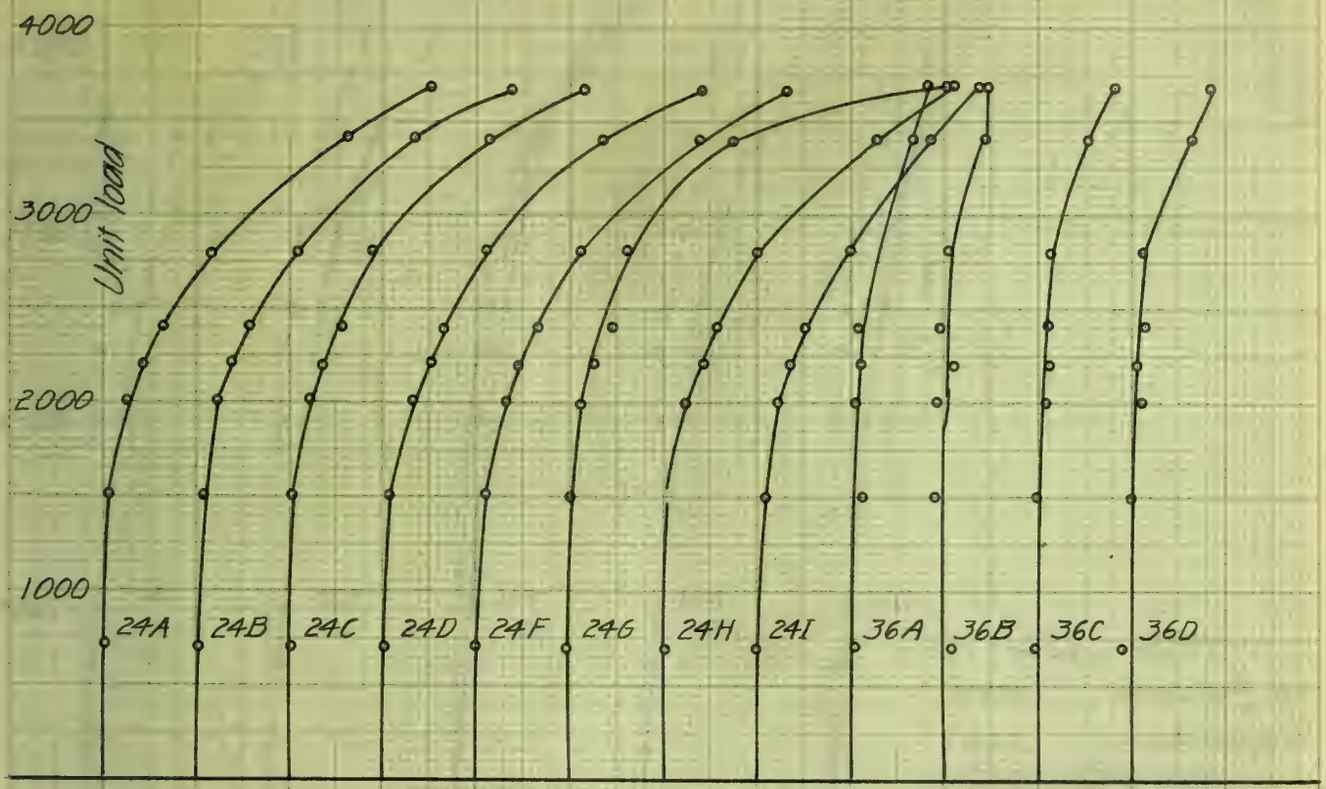

40000 #/in²
Tens.
4000
3000
2000
1000
Unit load
21
22
23
24
25
26
27
28
29
30



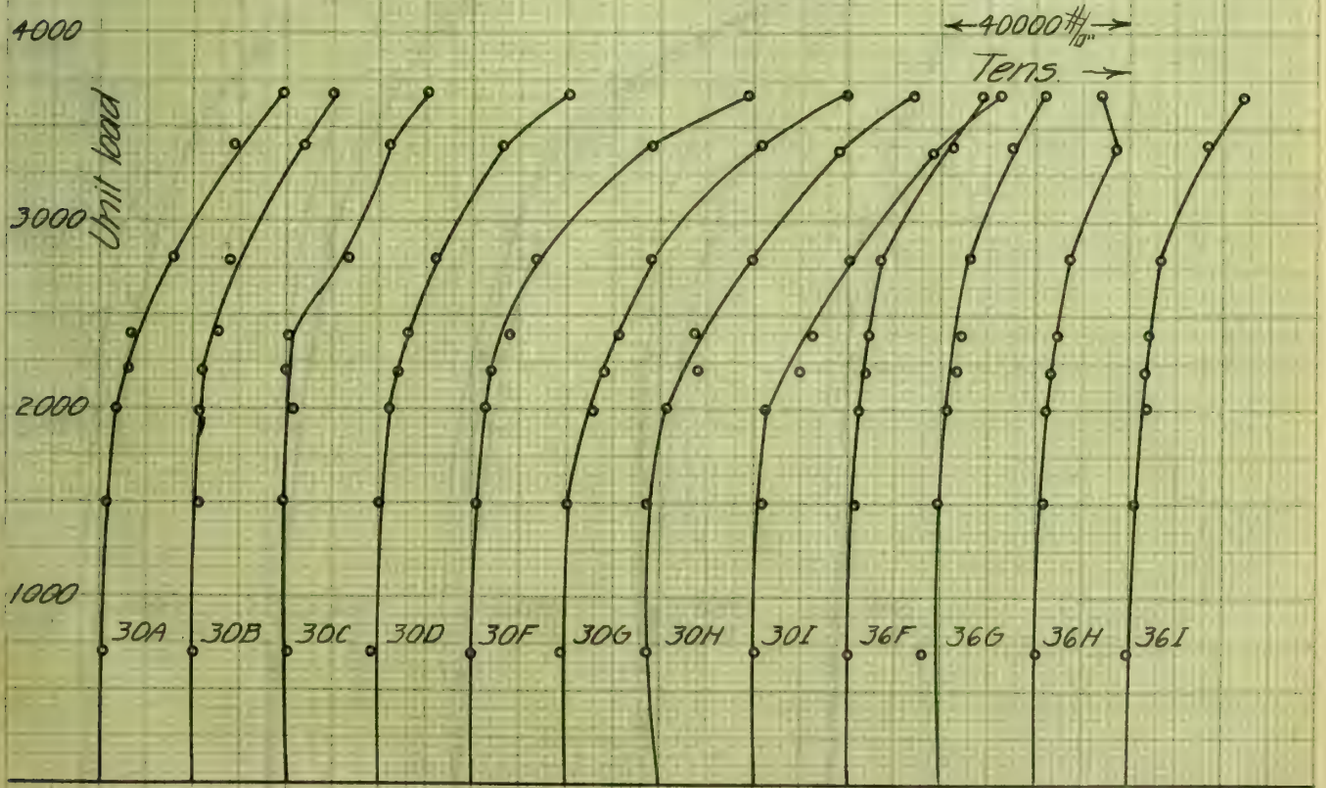

4000
3000
2000
1000
Unit load
11
12
13
14
15
16
17
18
19
COL. 8910
40000 #/in.
Tens.
4000
3000
2000
1000
Unit load
31
32
33
34
35
36
37
38
39

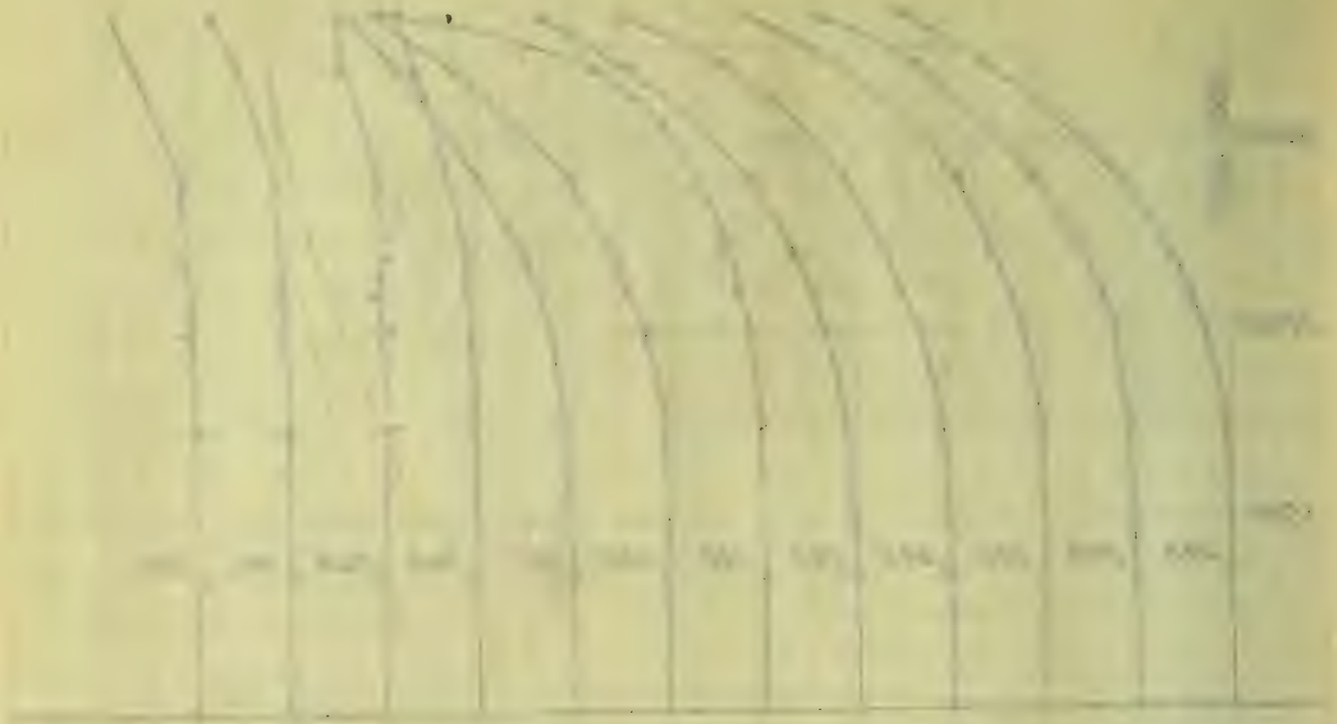


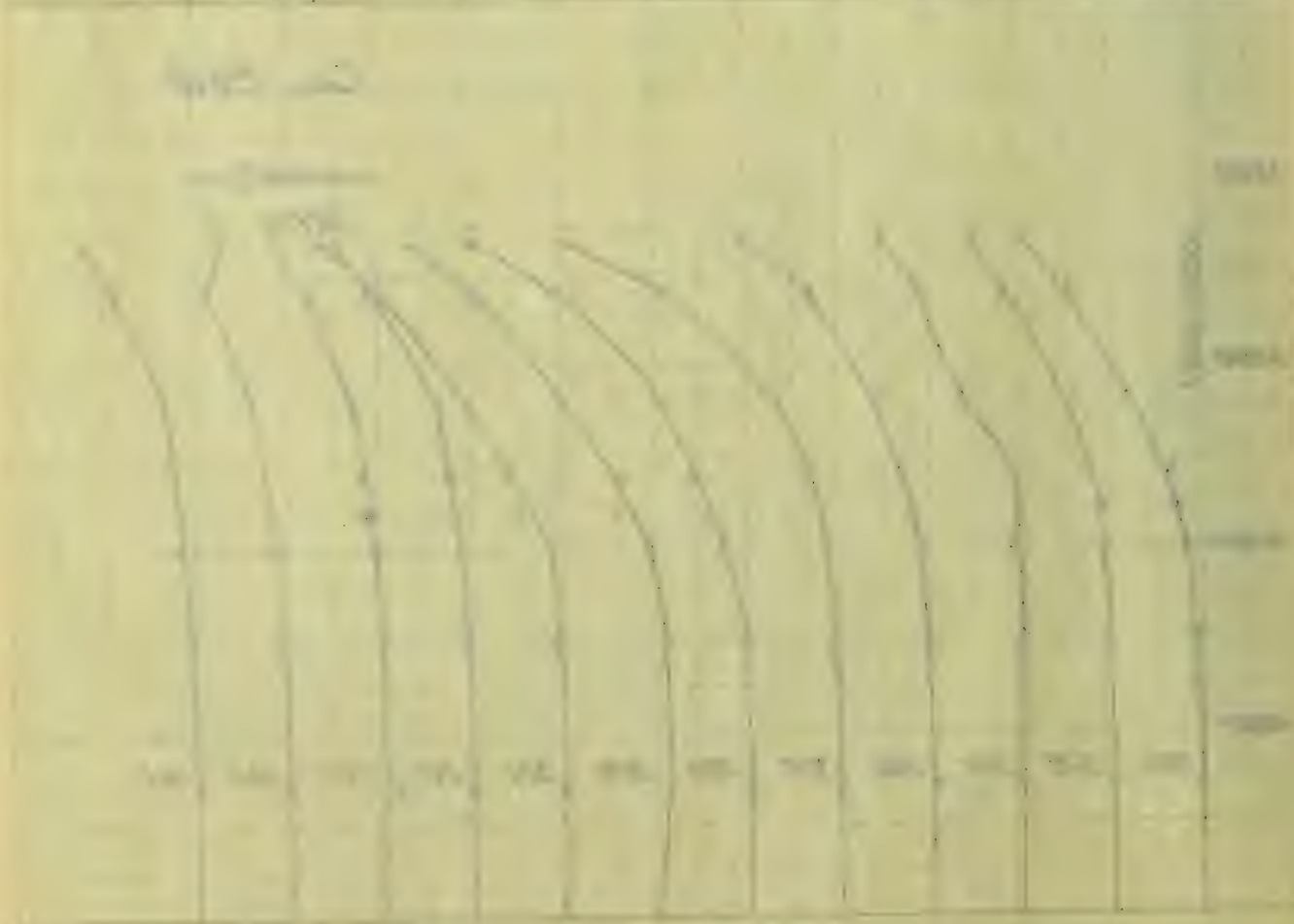


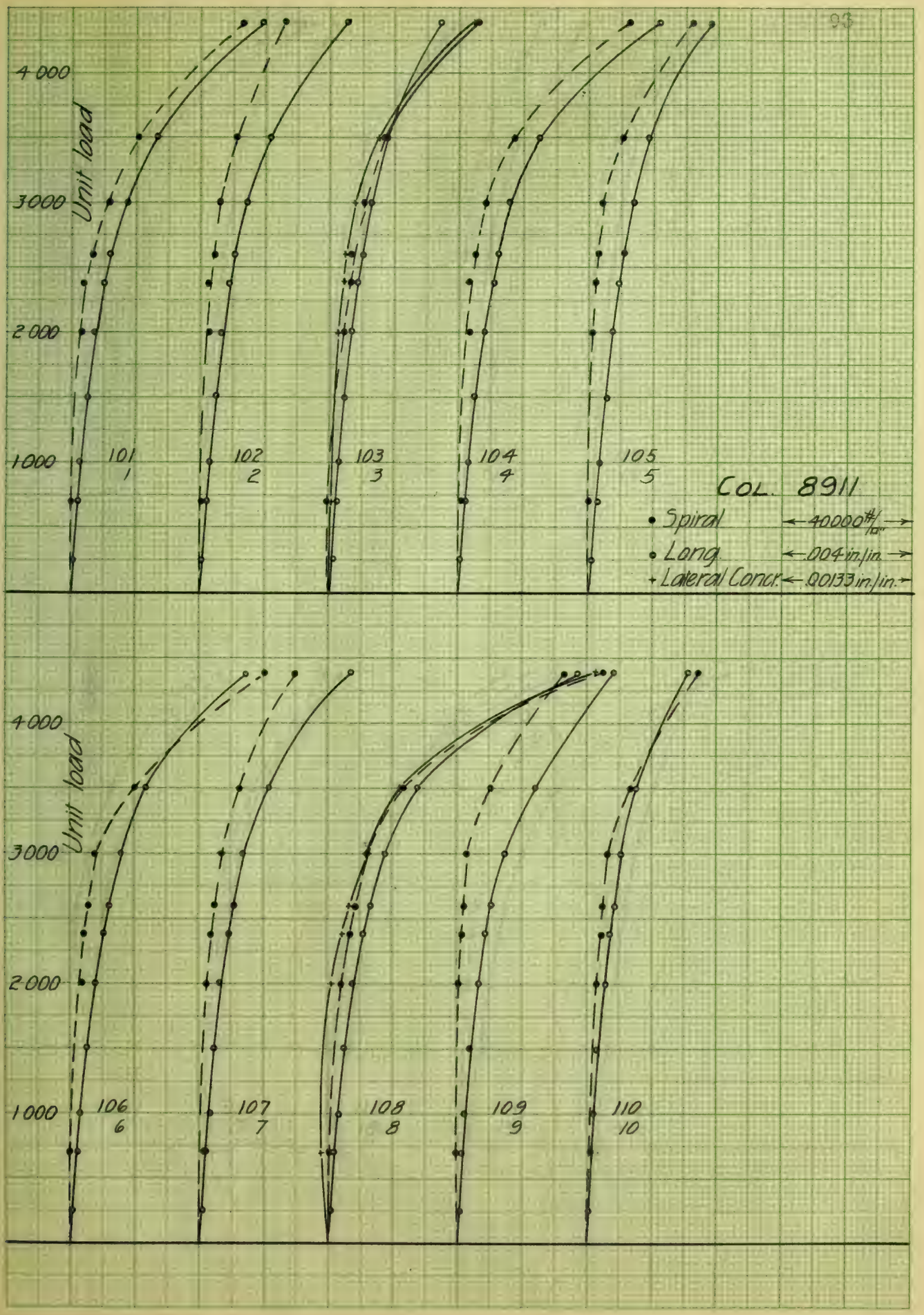

4000
3000
2000
1000
Unit load
24A
24B
24C
24D
24F
24G
24H
24I
36A
36B
36C
36D

COL. 8910

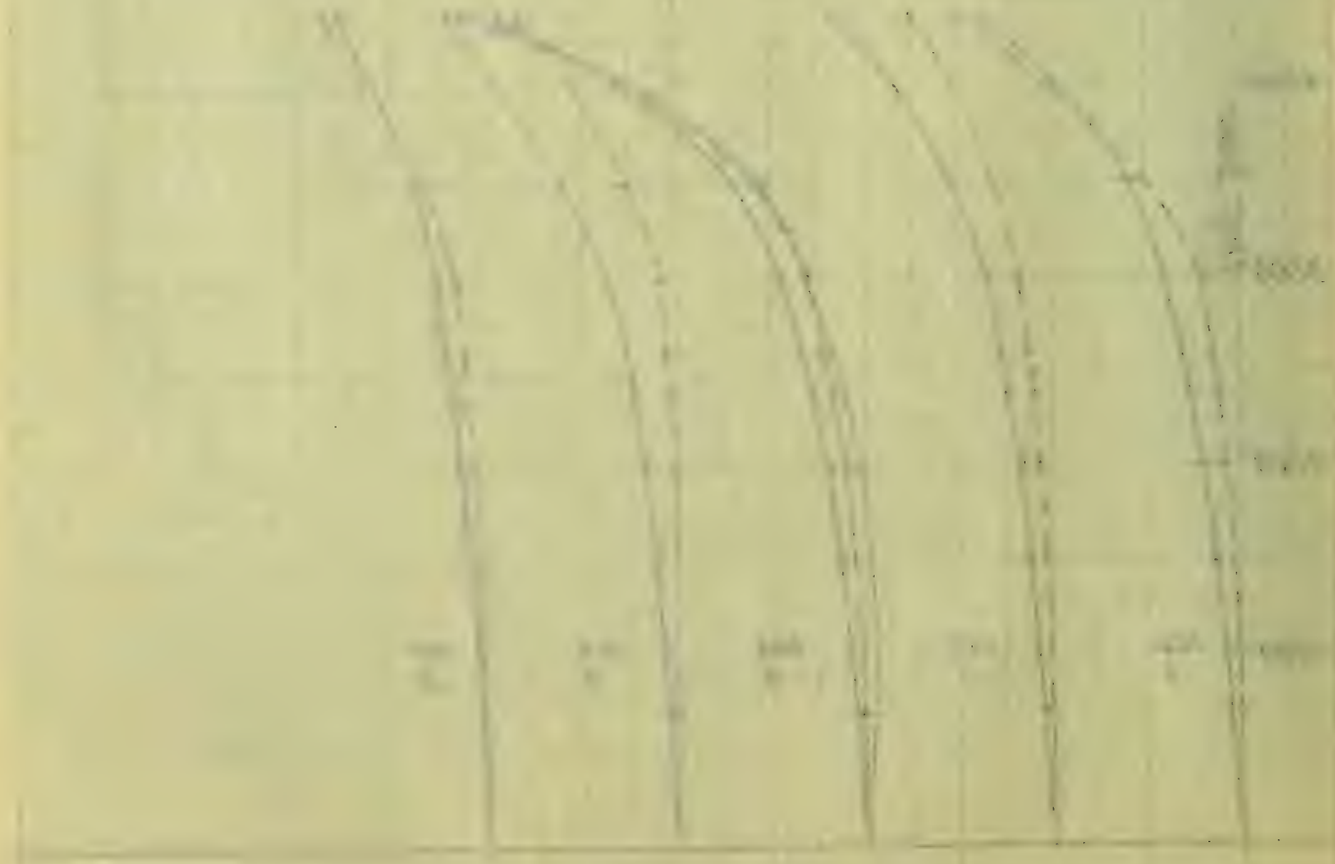

4000
3000
2000
1000
Unit load
40000 #/in²
Tens.
30A
30B
30C
30D
30F
30G
30H
30I
36F
36G
36H
36I

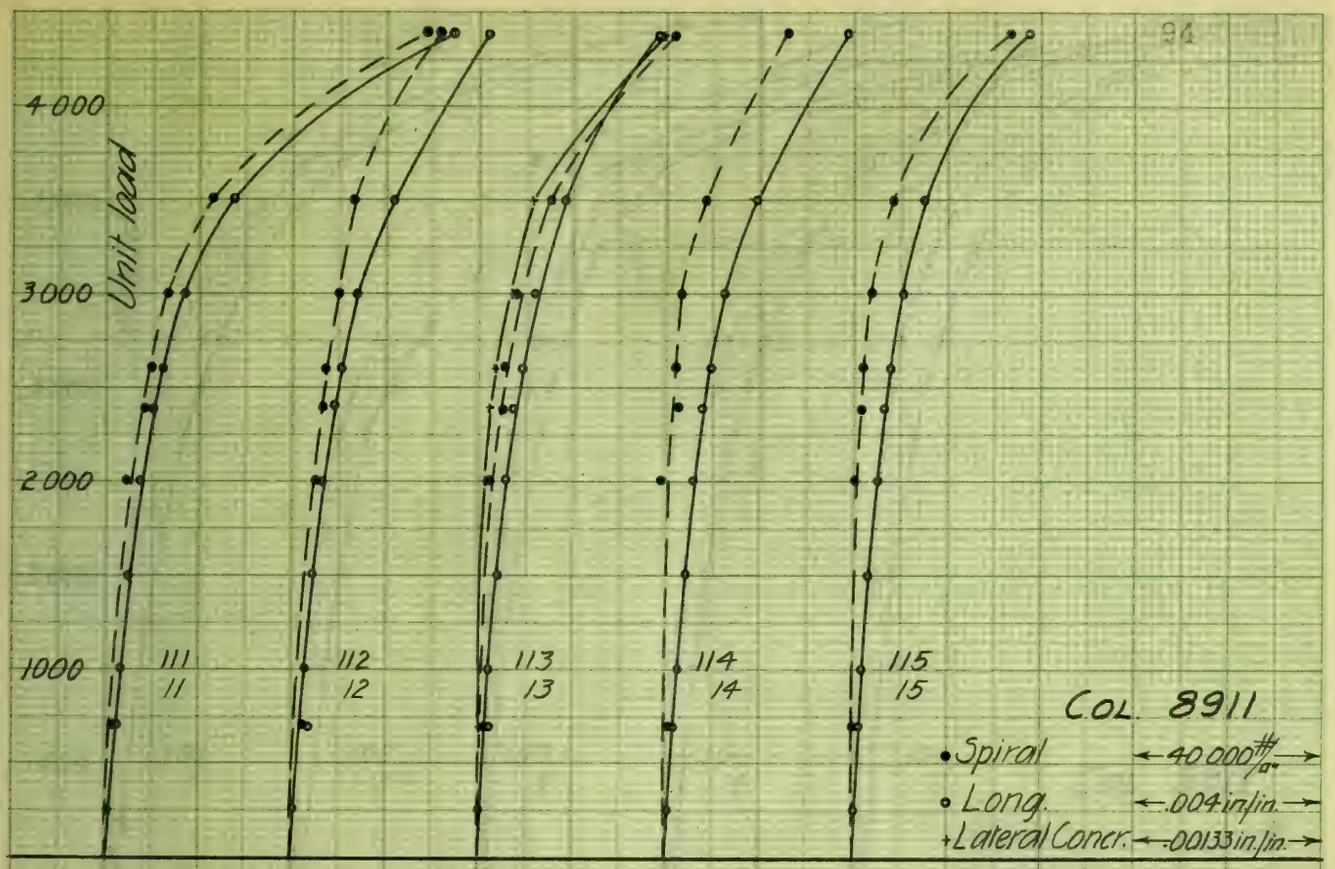


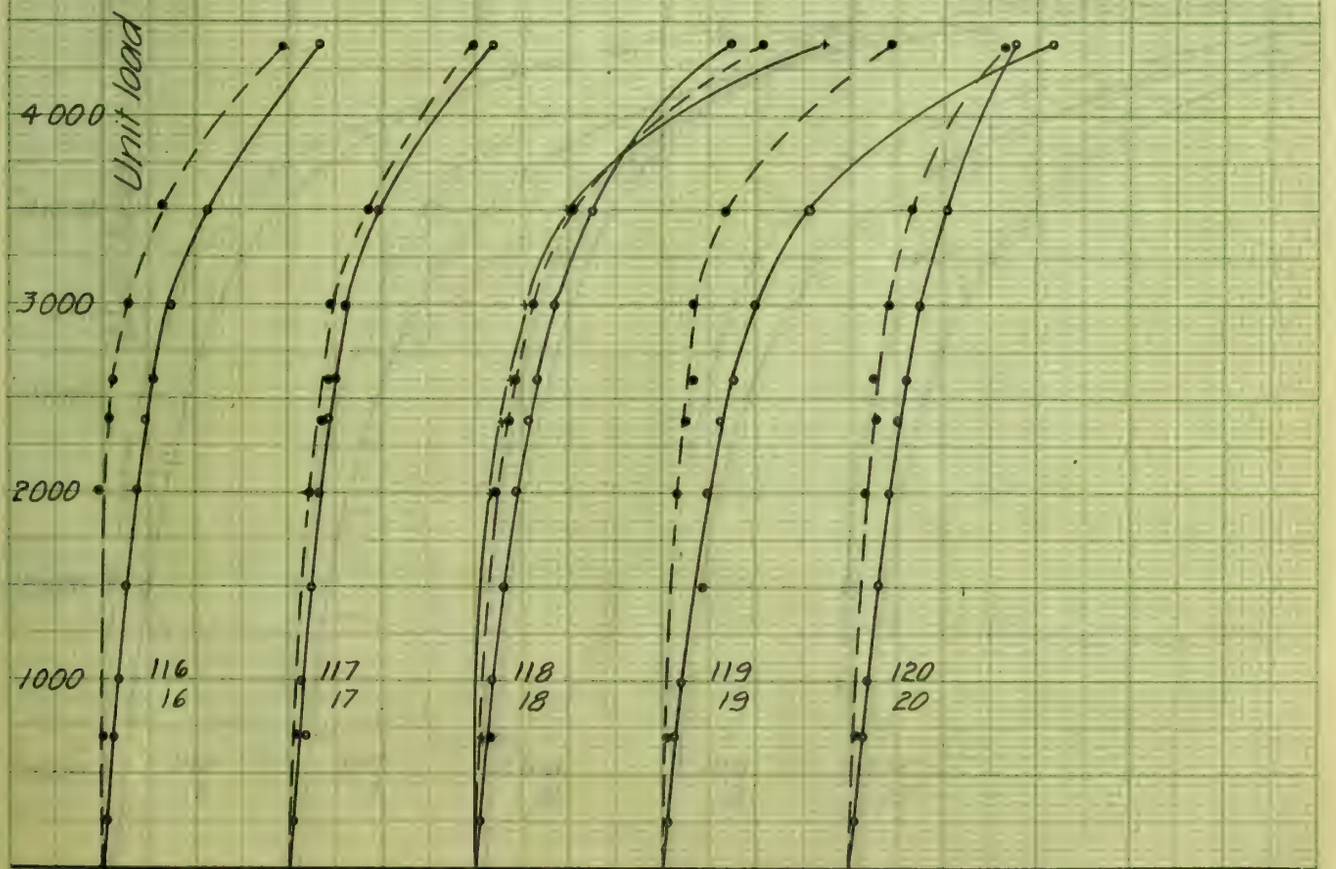


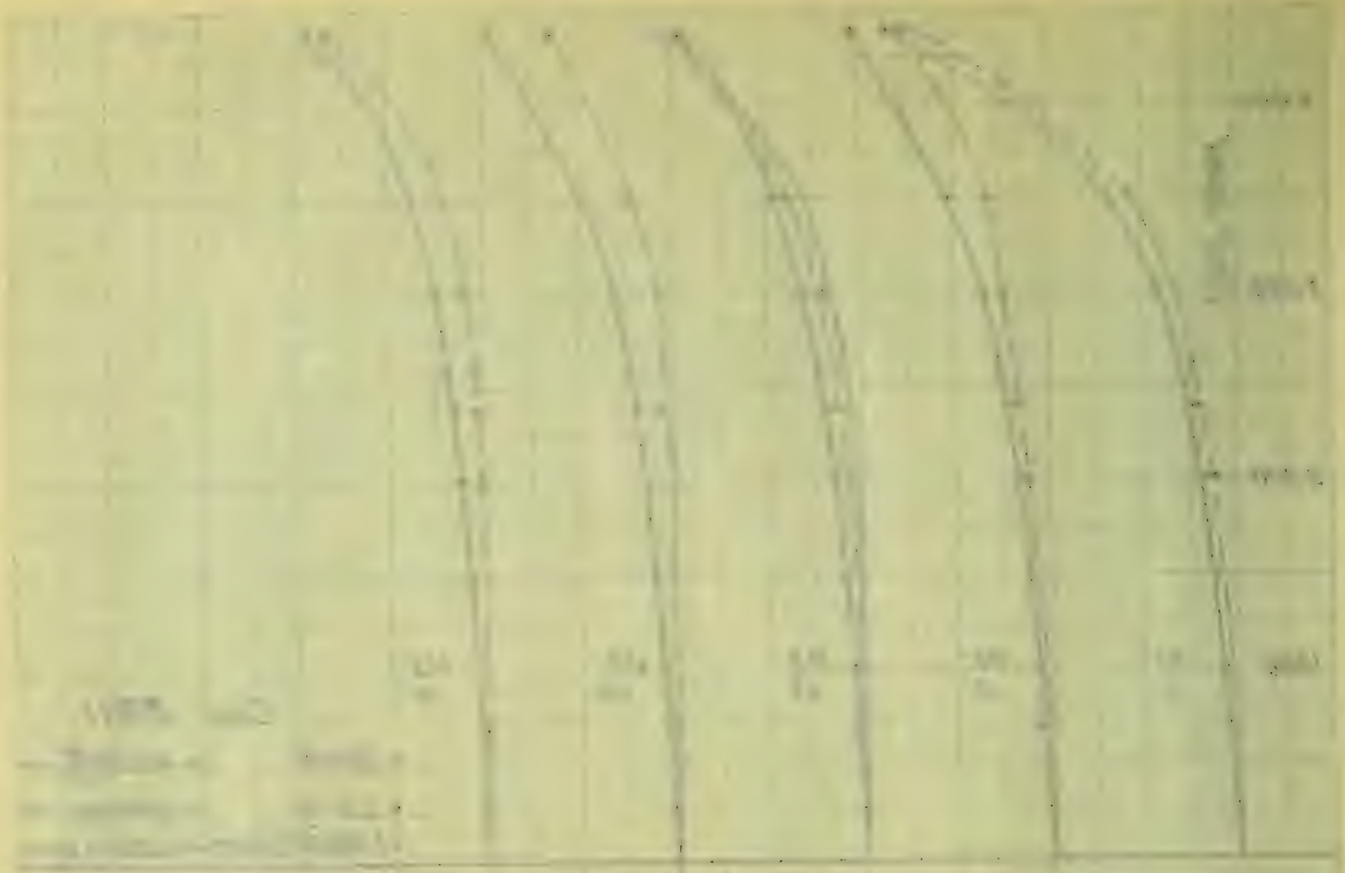

4000
3000
2000
1000
Unit load
101
1
102
2
103
3
104
4
105
5
COL. 8911
• Spiral ← 40000 #/in² →
• Long. ← .004 in./in. →
+ Lateral Concr. ← .00133 in./in. →
4000
3000
2000
1000
Unit load
106
6
107
7
108
8
109
9
110
10



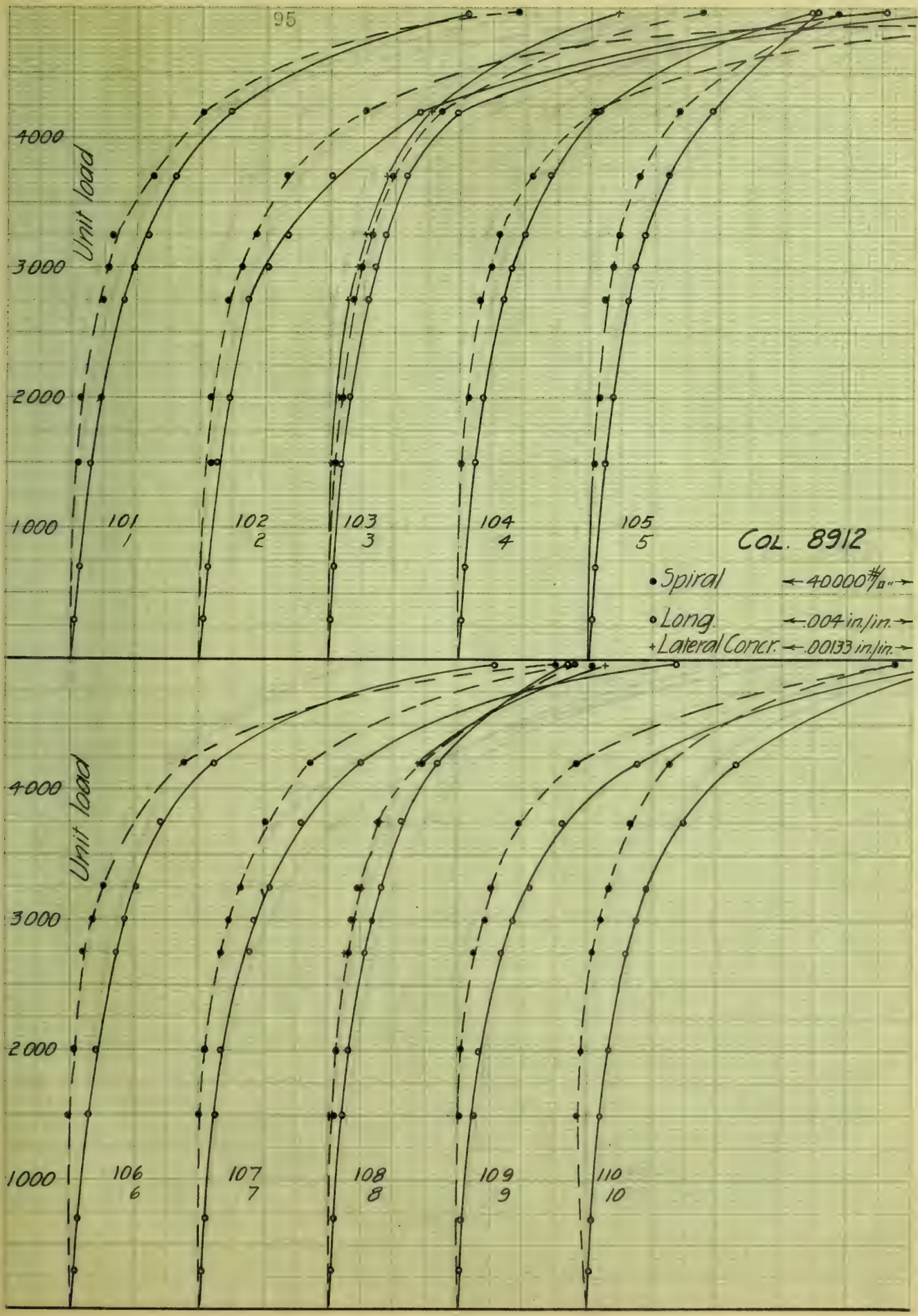


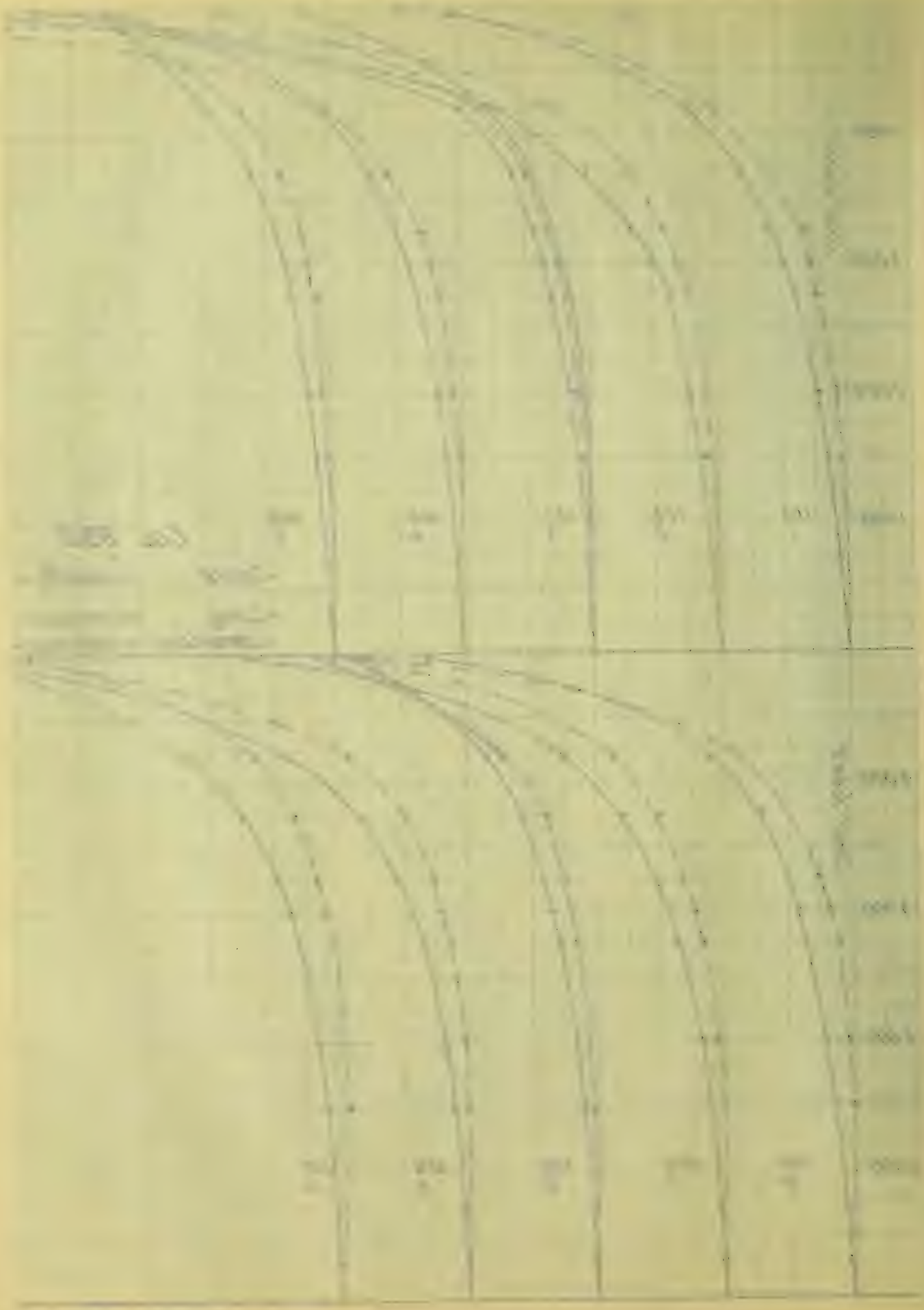

4000
3000
2000
1000
Unit load
111
11
112
12
113
13
114
14
115
15
Col. 8911
• Spiral ← 40 000 #/□" →
○ Long. ← .004 in./in. →
+ Lateral Concr. ← .00133 in./in. →

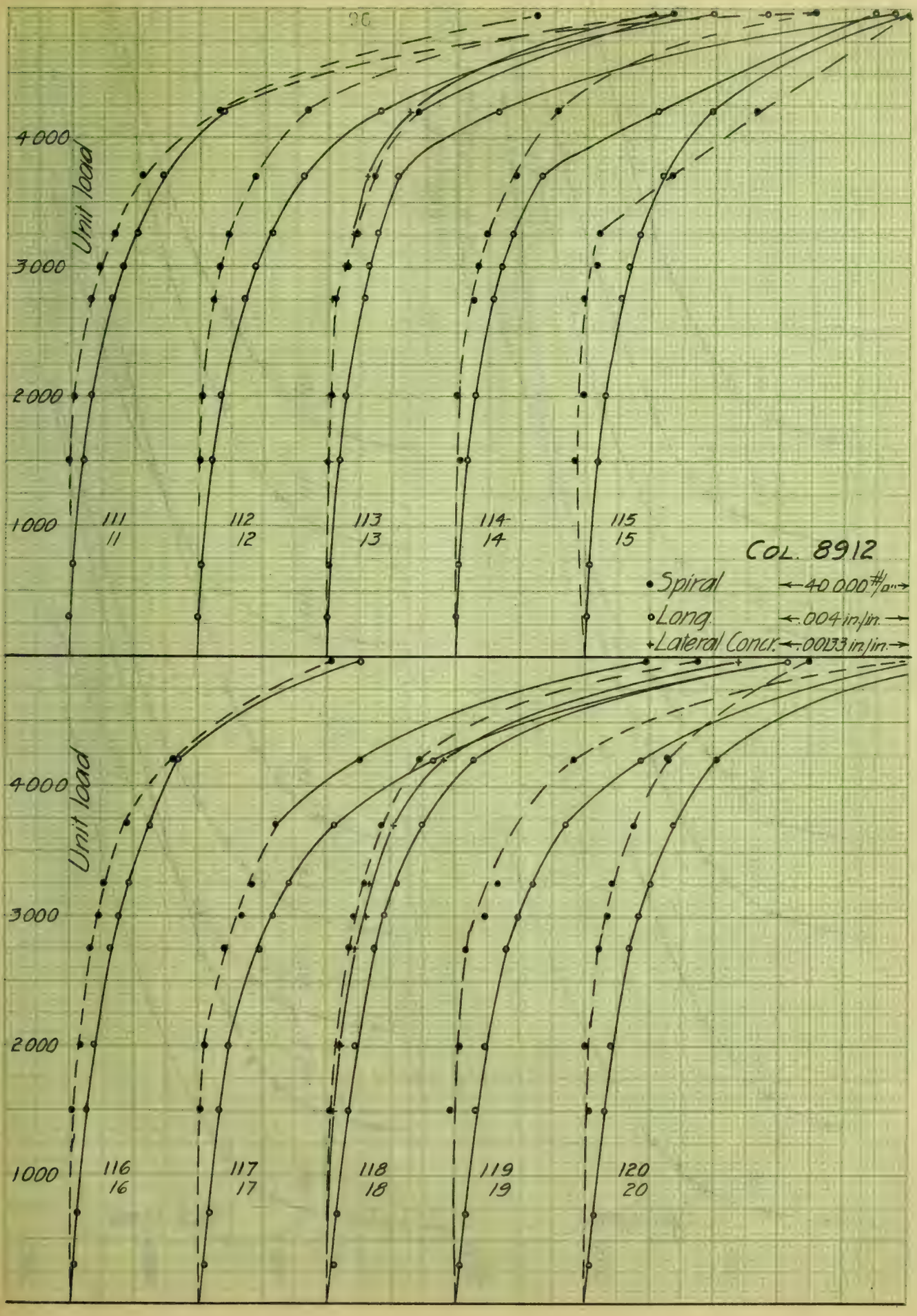

4000
3000
2000
1000
Unit load
116
16
117
17
118
18
119
19
120
20

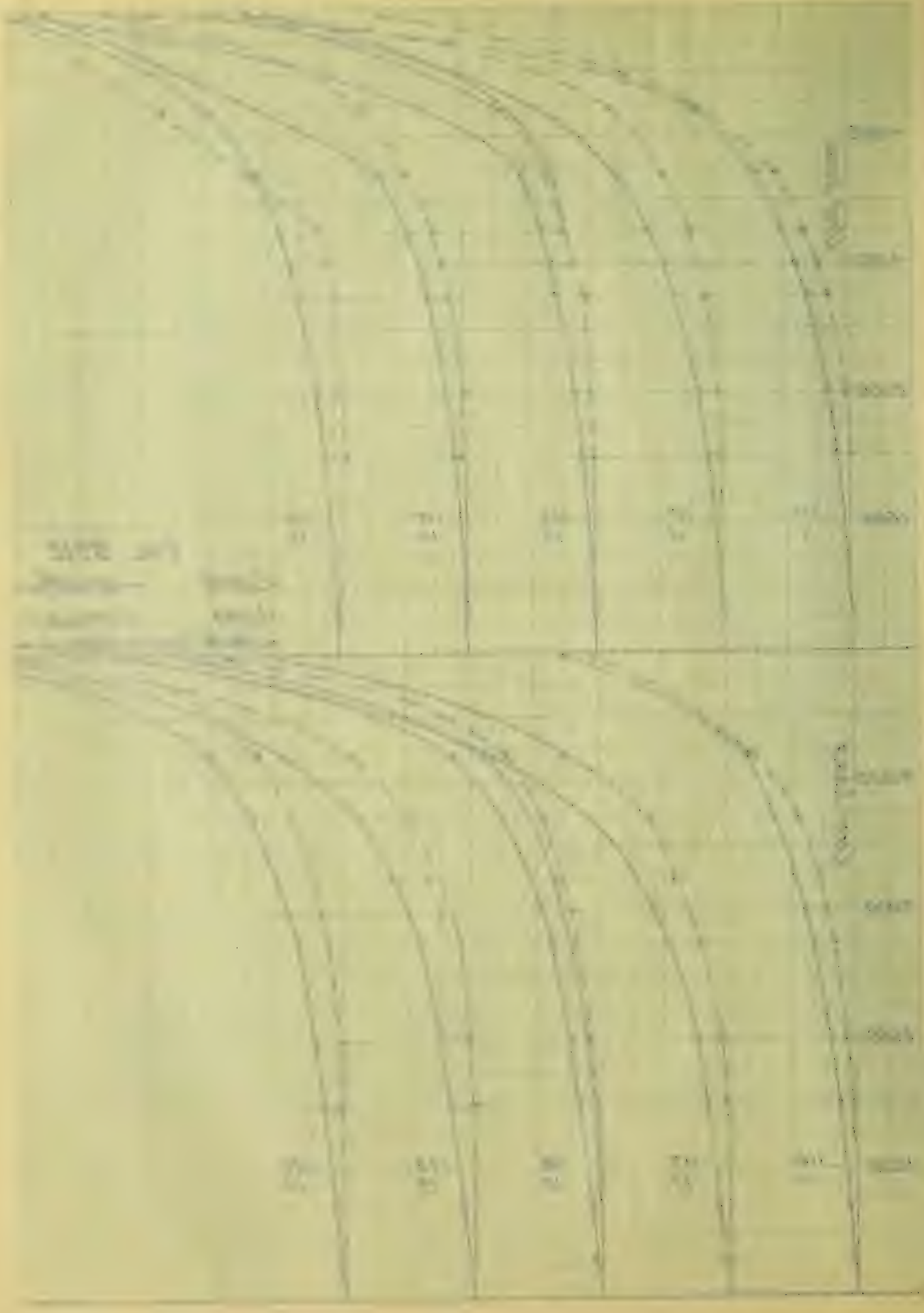


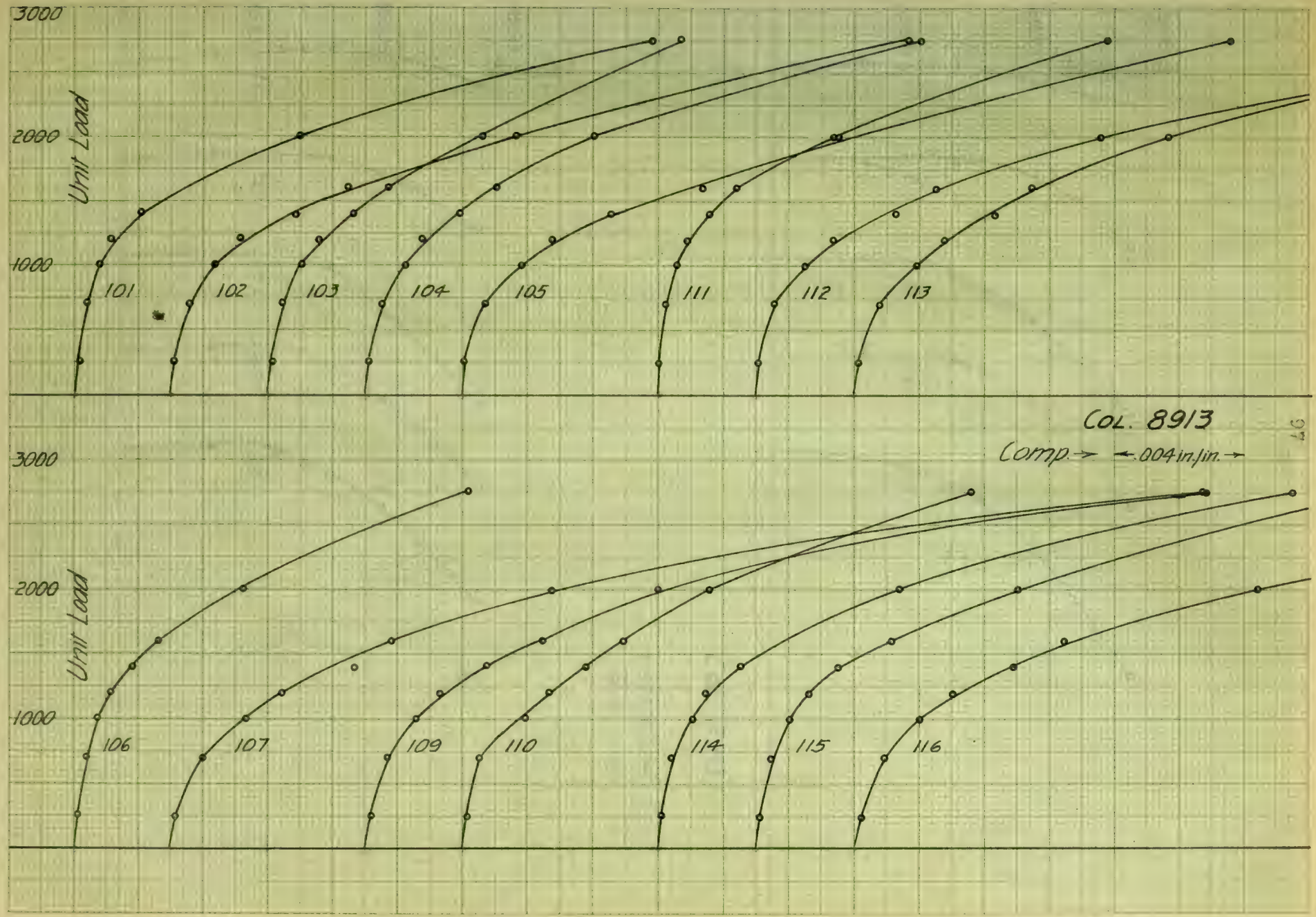


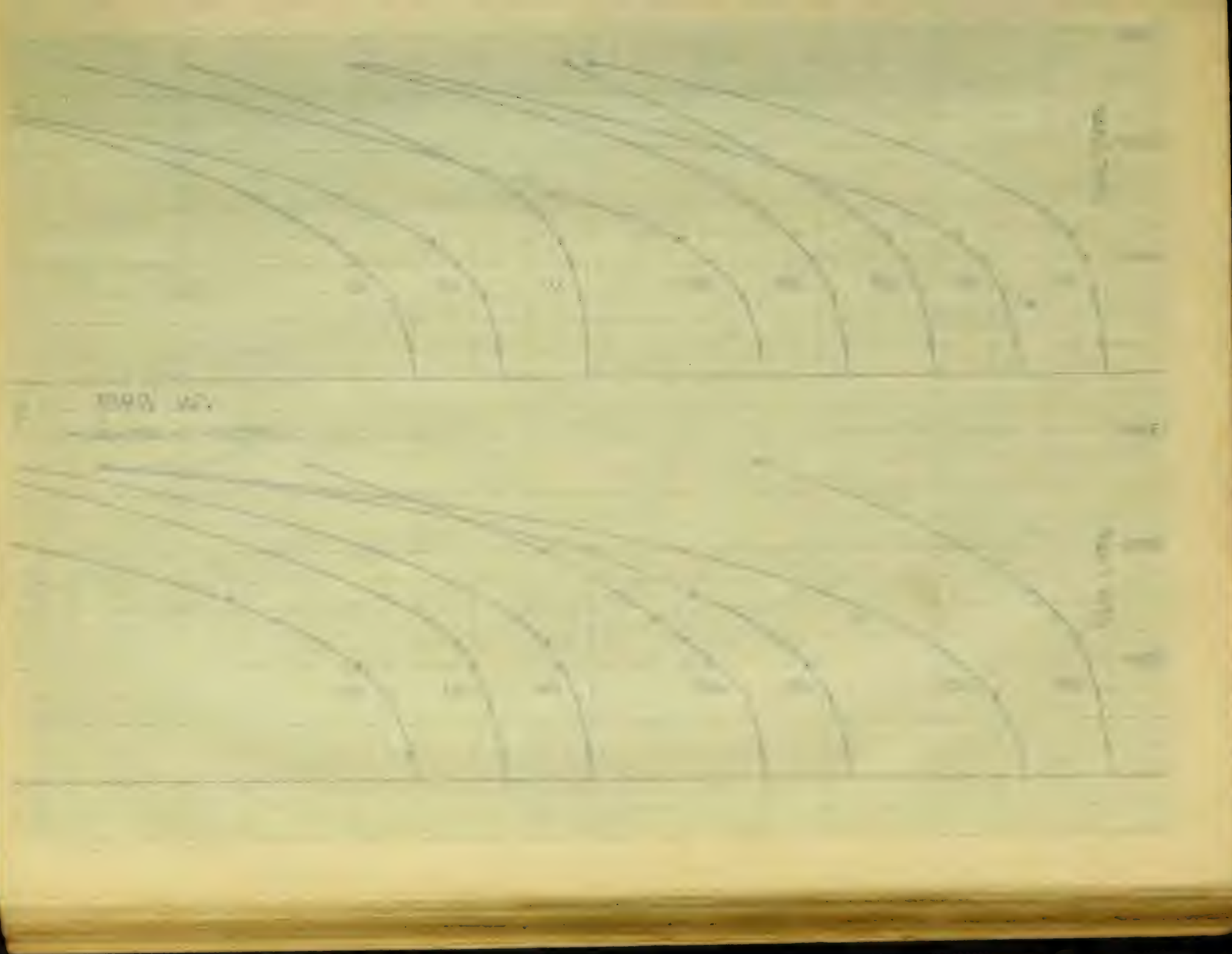

4000
3000
2000
1000
Unit load
101
1
102
2
103
3
104
4
105
5
COL. 8912
• Spiral ← 40000 #/□" →
• Long. ← .004 in./in. →
+ Lateral Concr. ← .00133 in./in. →
4000
3000
2000
1000
Unit load
106
6
107
7
108
8
109
9
110
10

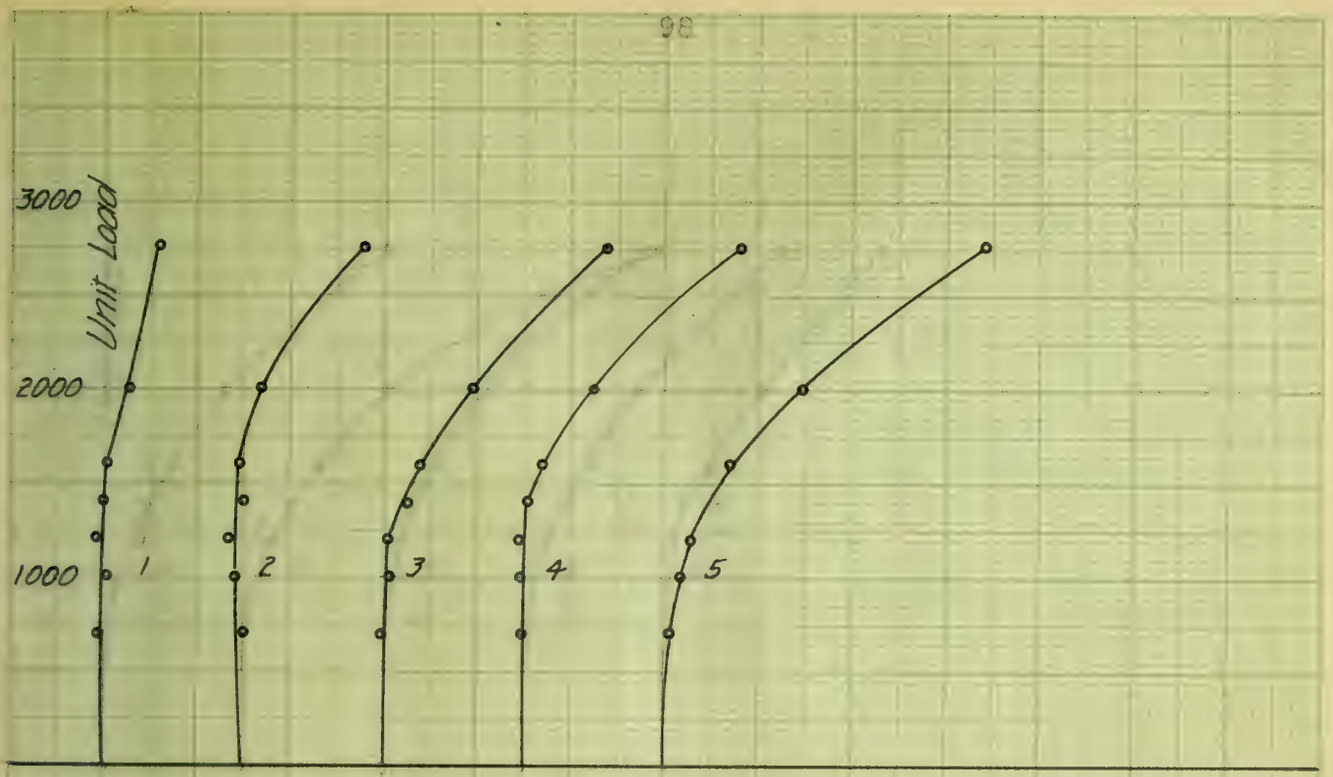



4000
3000
2000
1000
Unit load
111
11
112
12
113
13
114
14
115
15
COL. 8912
• Spiral ← 40 000 #/o.. →
◦ Long. ← .004 in./in. →
+ Lateral Concr. ← .00133 in./in. →
4000
3000
2000
1000
Unit load
116
16
117
17
118
18
119
19
120
20



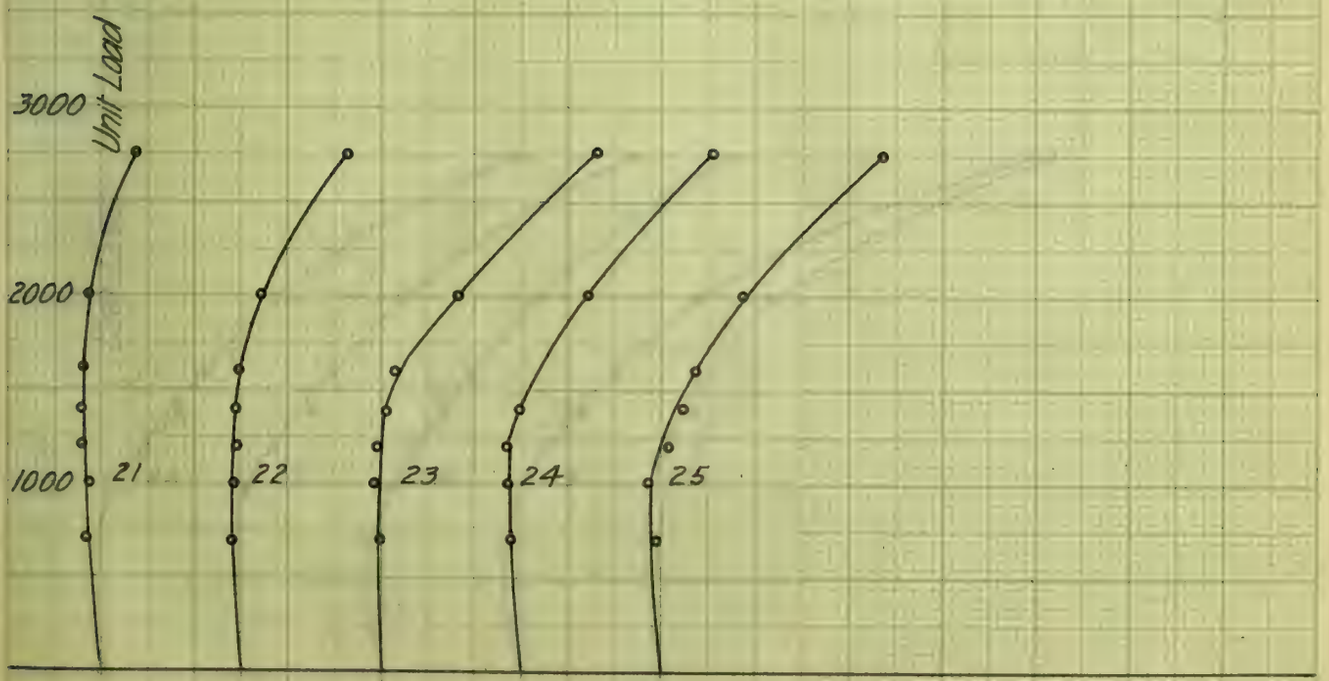

3000
2000
1000
Unit Load
101
102
103
104
105
111
112
113
Col. 8913
Comp. → ← .004 in/in. →
3000
2000
1000
Unit Load
106
107
109
110
114
115
116





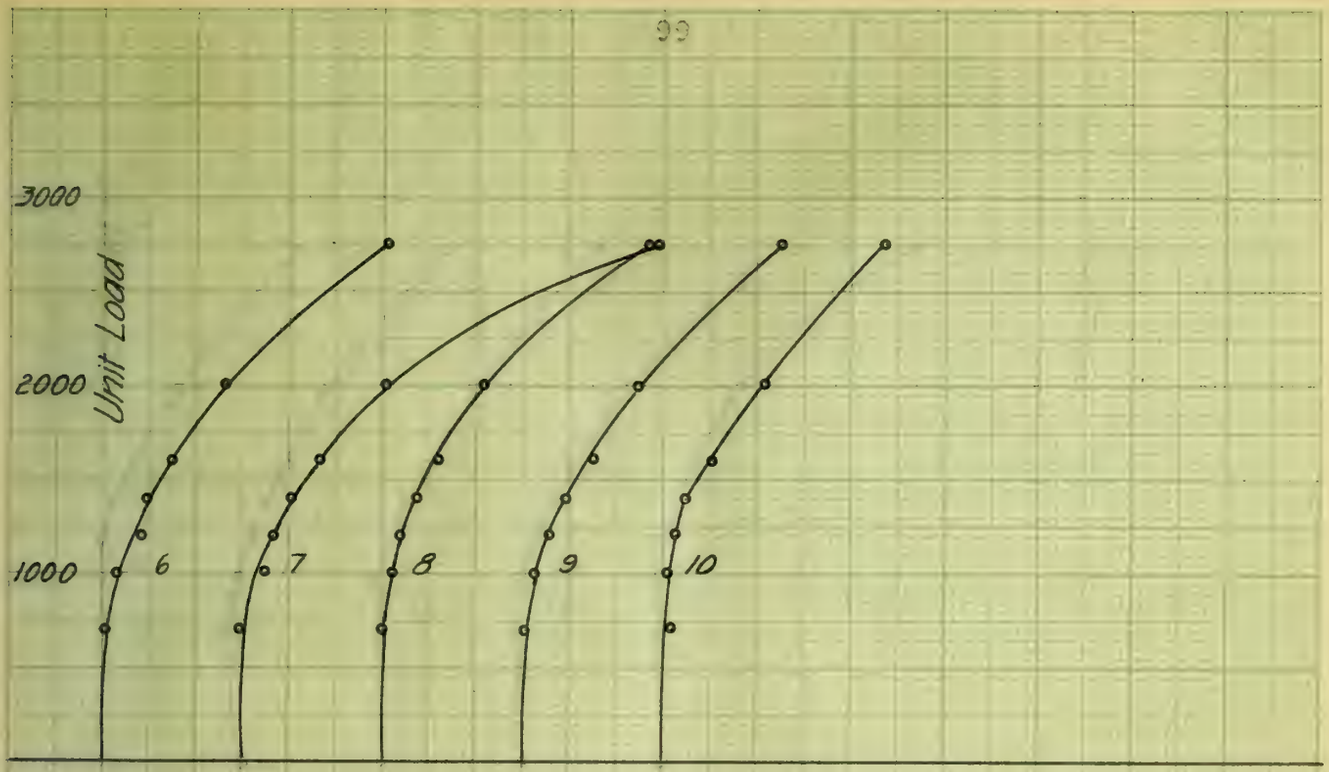
Col. 8913

←40000#/□"→
Tens. →



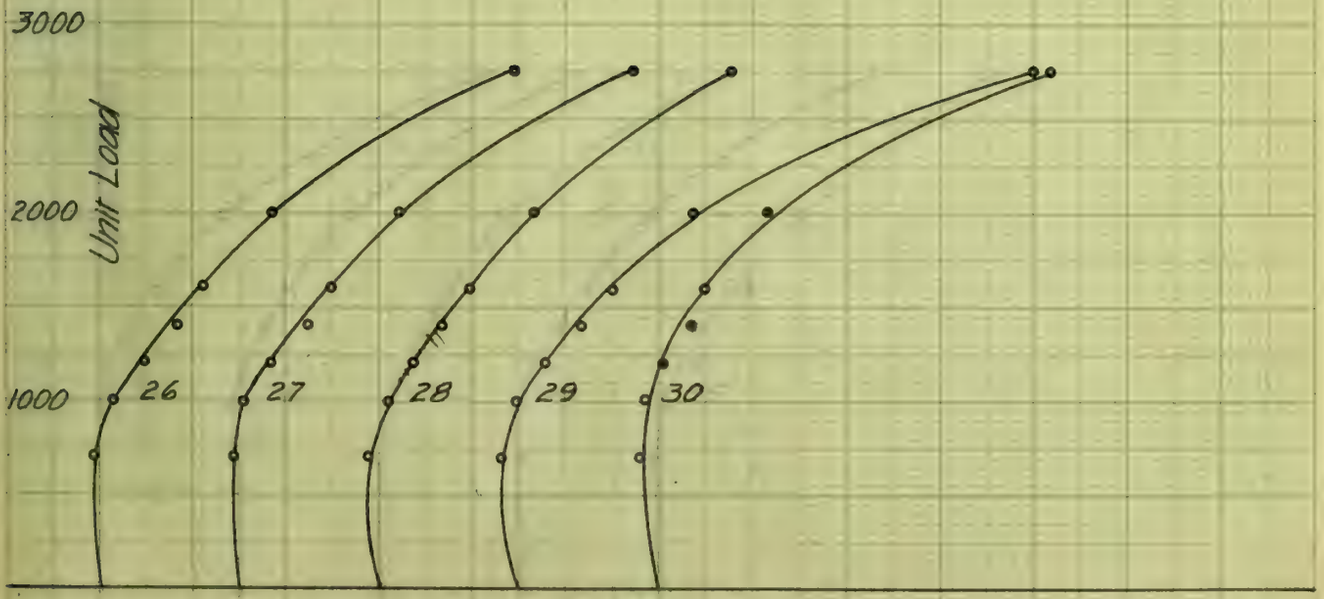






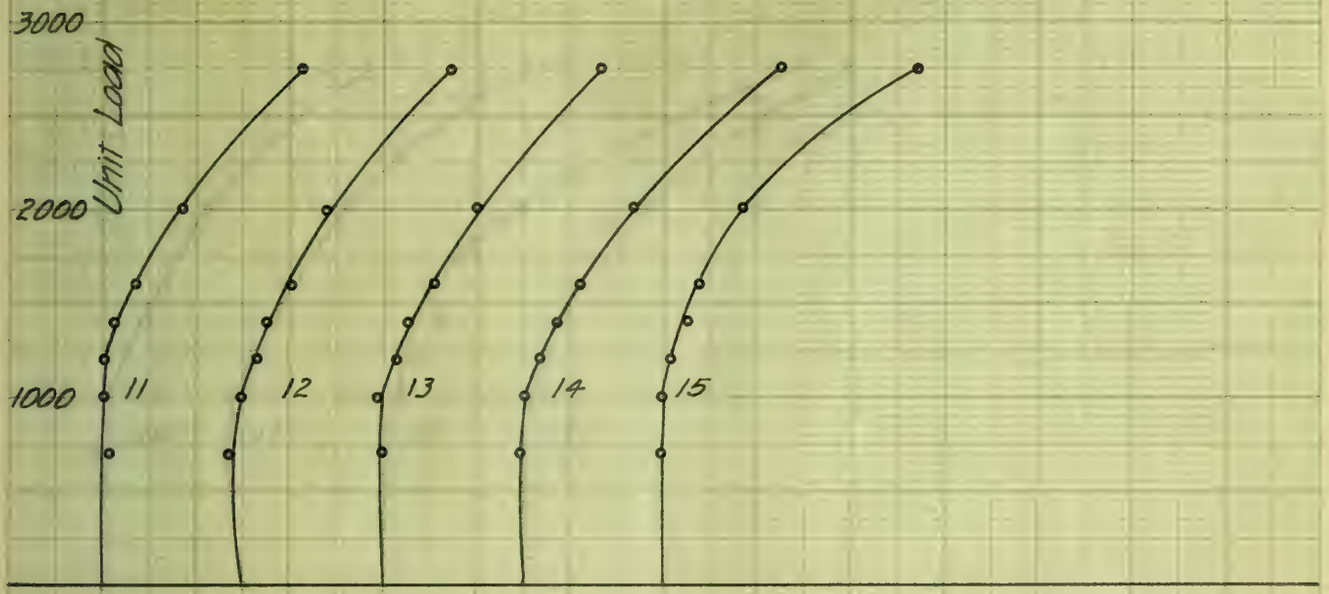
COL. 8913

← 40000 #/in →
Tens. →



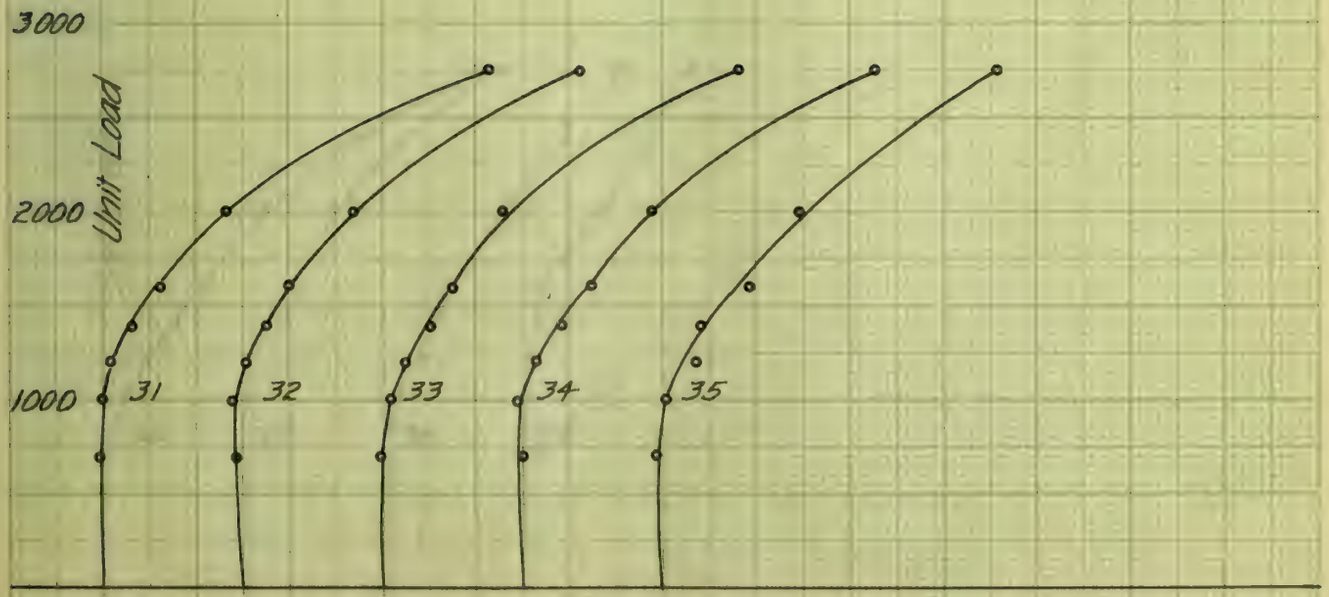






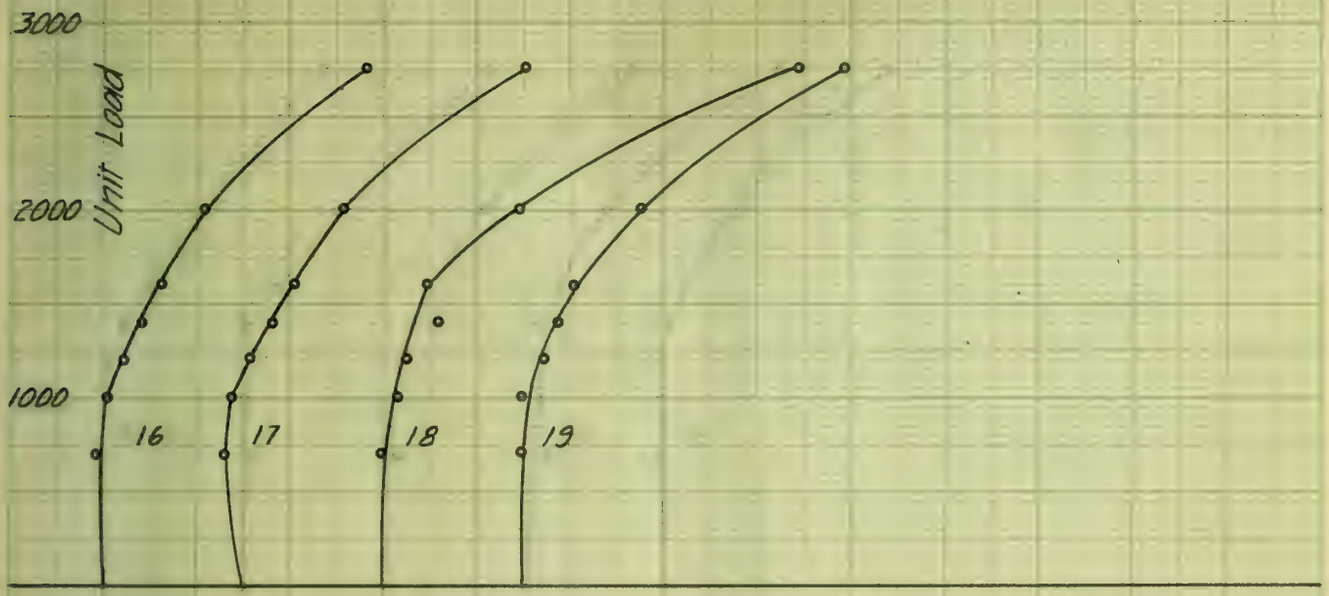
COL. 8913

←40000#/□"→
Tens. →



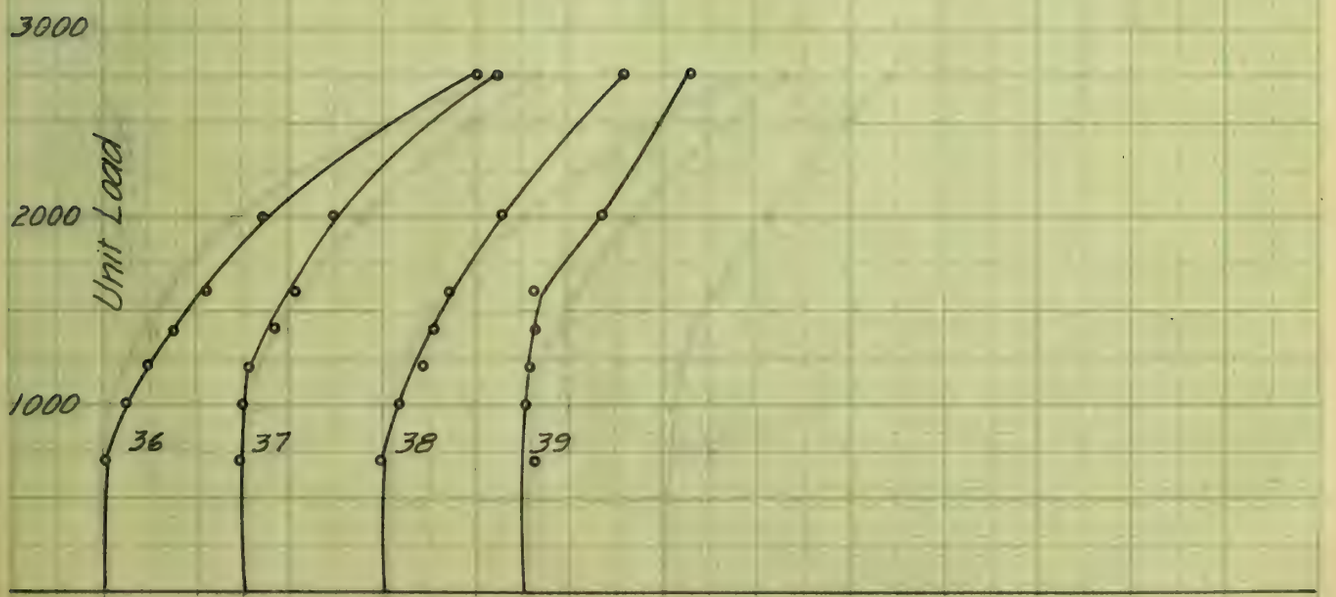






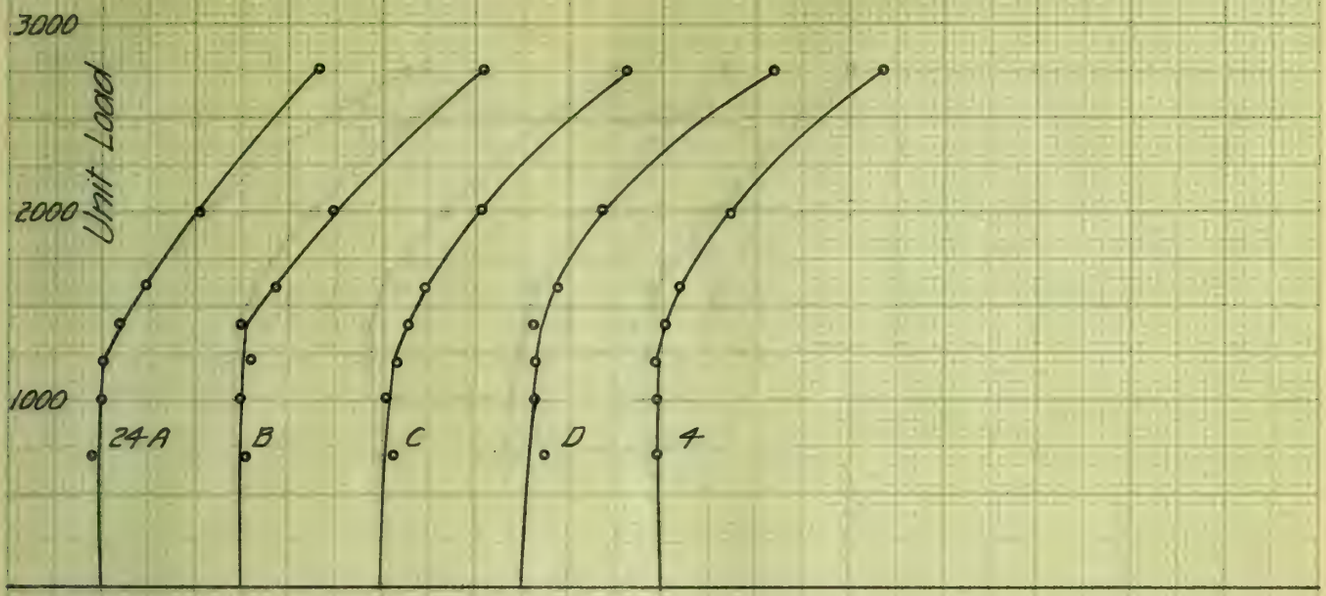
COL. 8913

←40000#/□"→
Tens. →



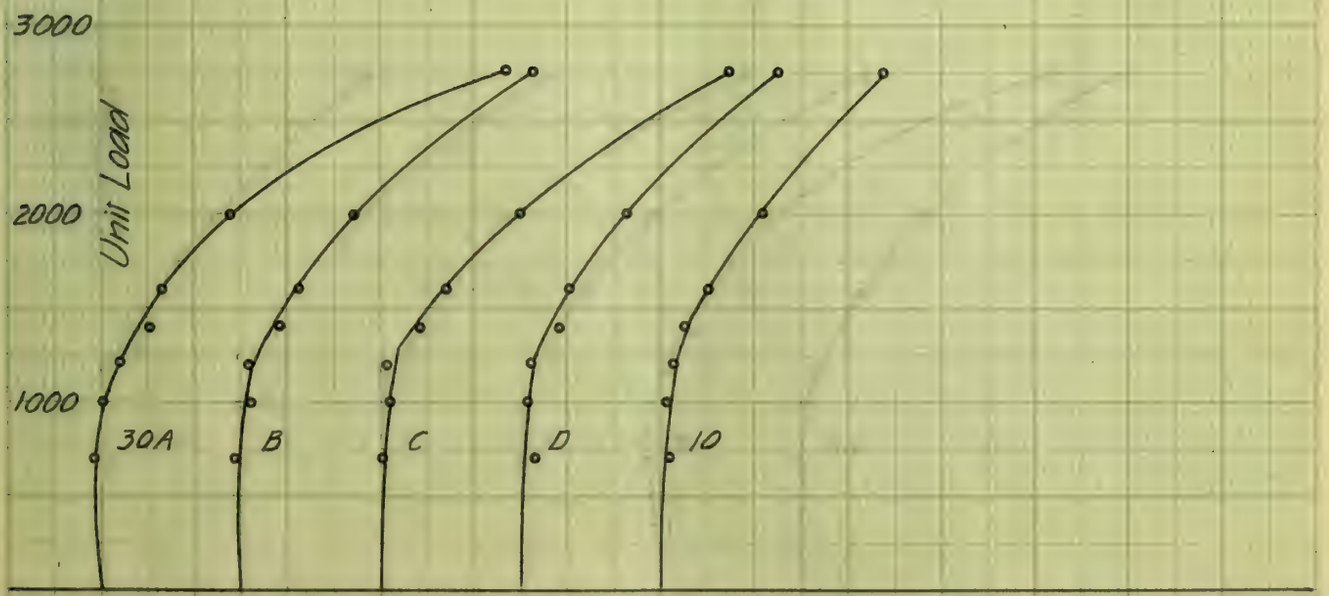


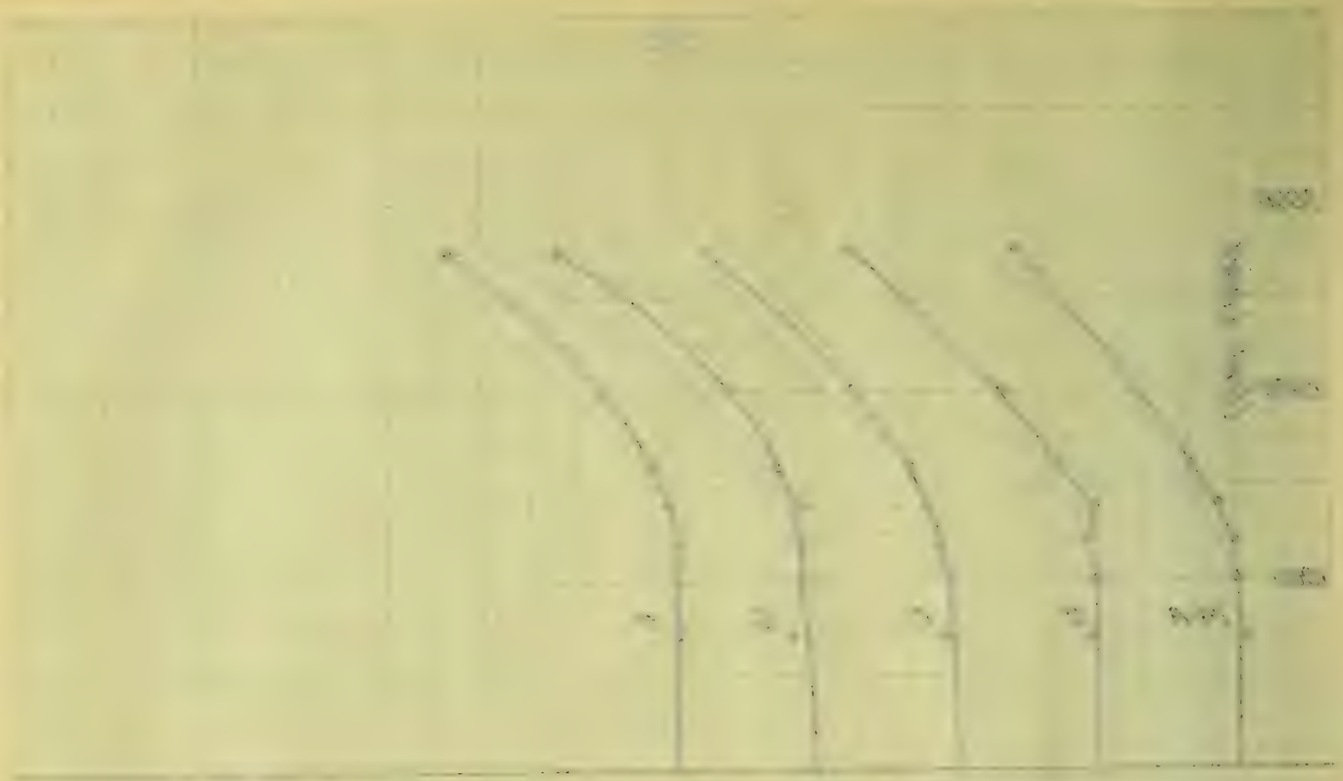




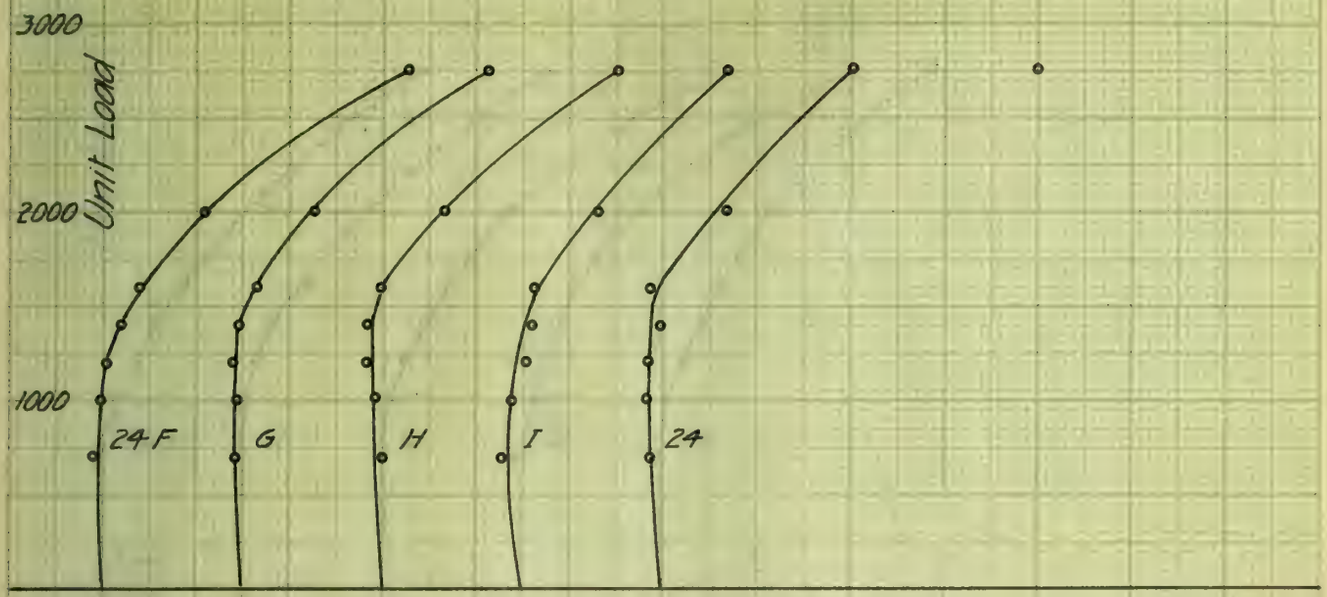
Col. 8913

← 40000 #/□" →
Tens. →



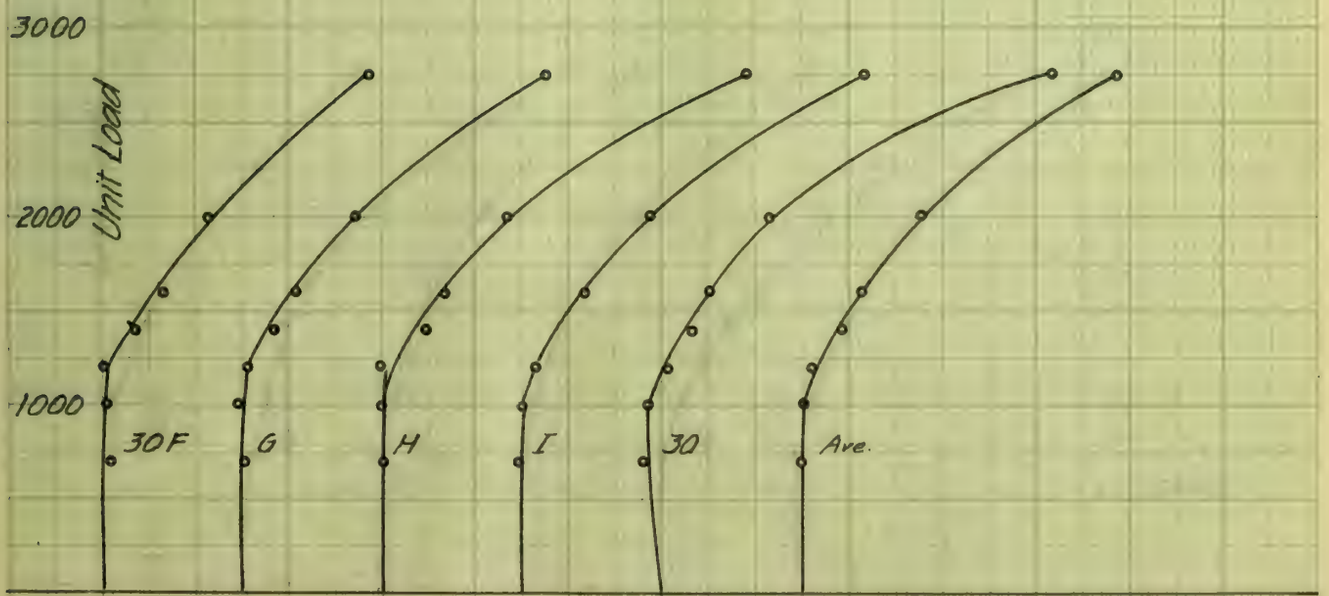






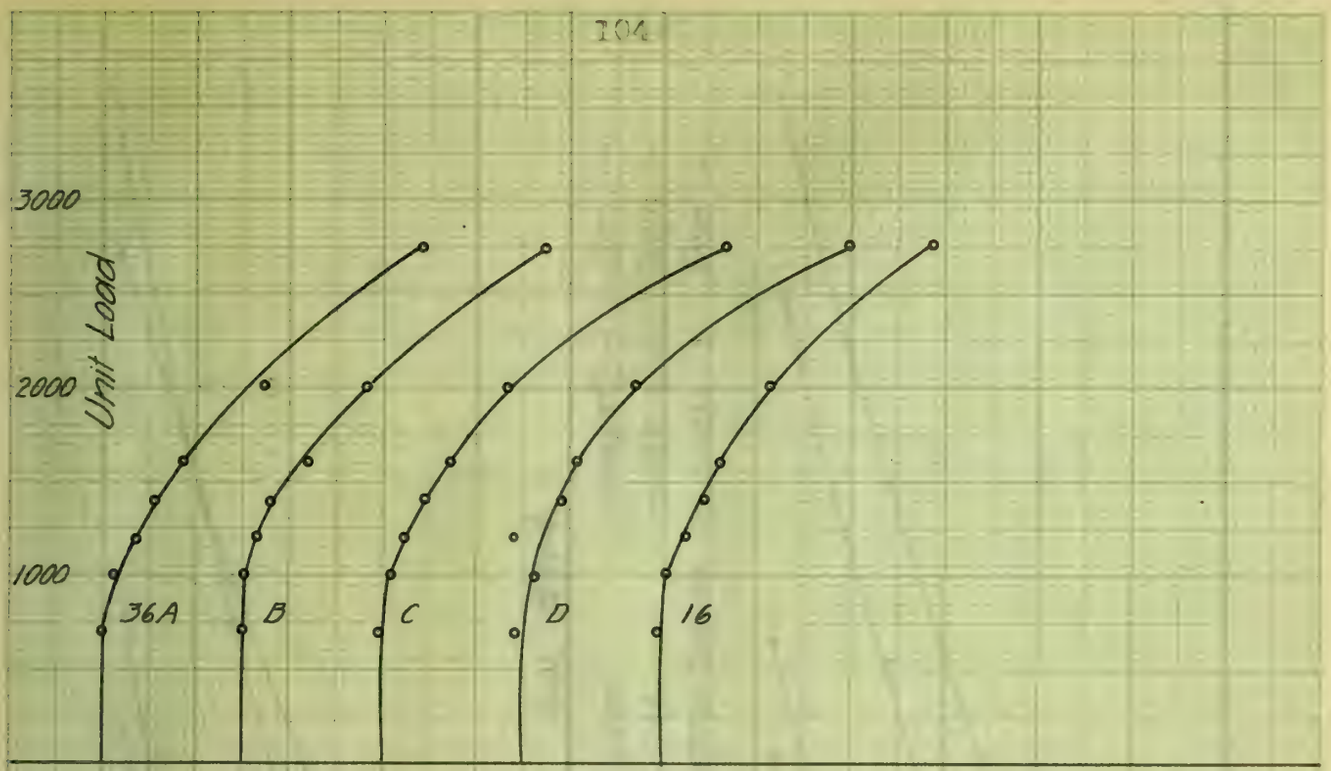
COL. 8913

← 40000 #/□" →
Tens. →



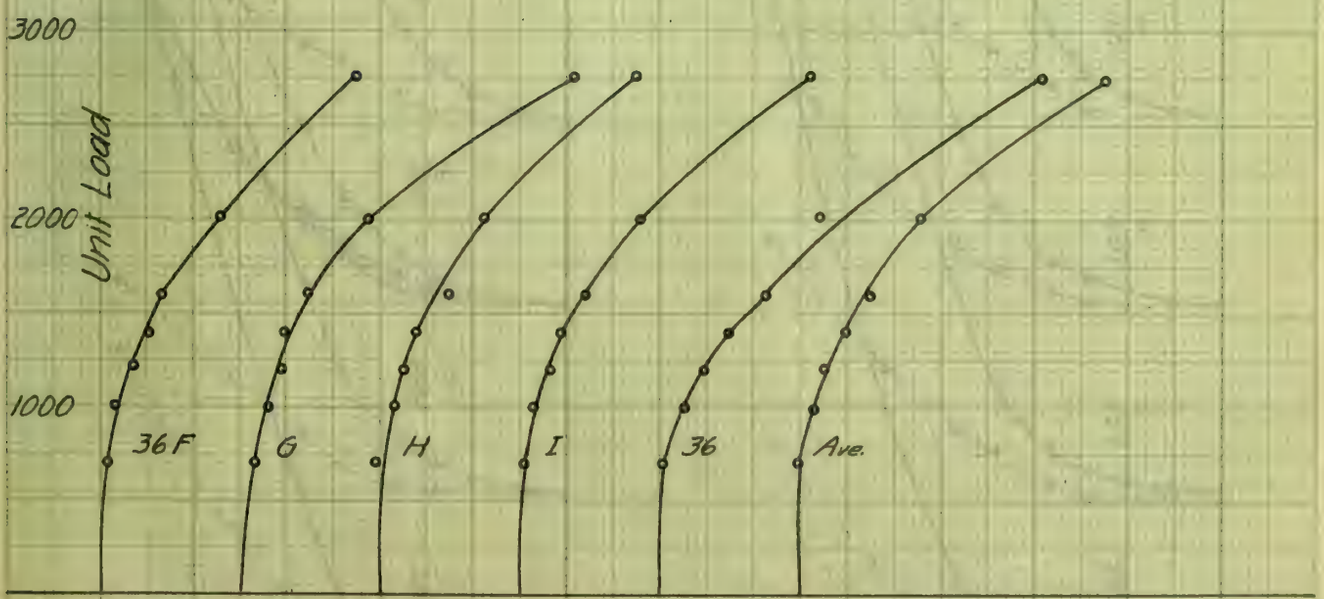


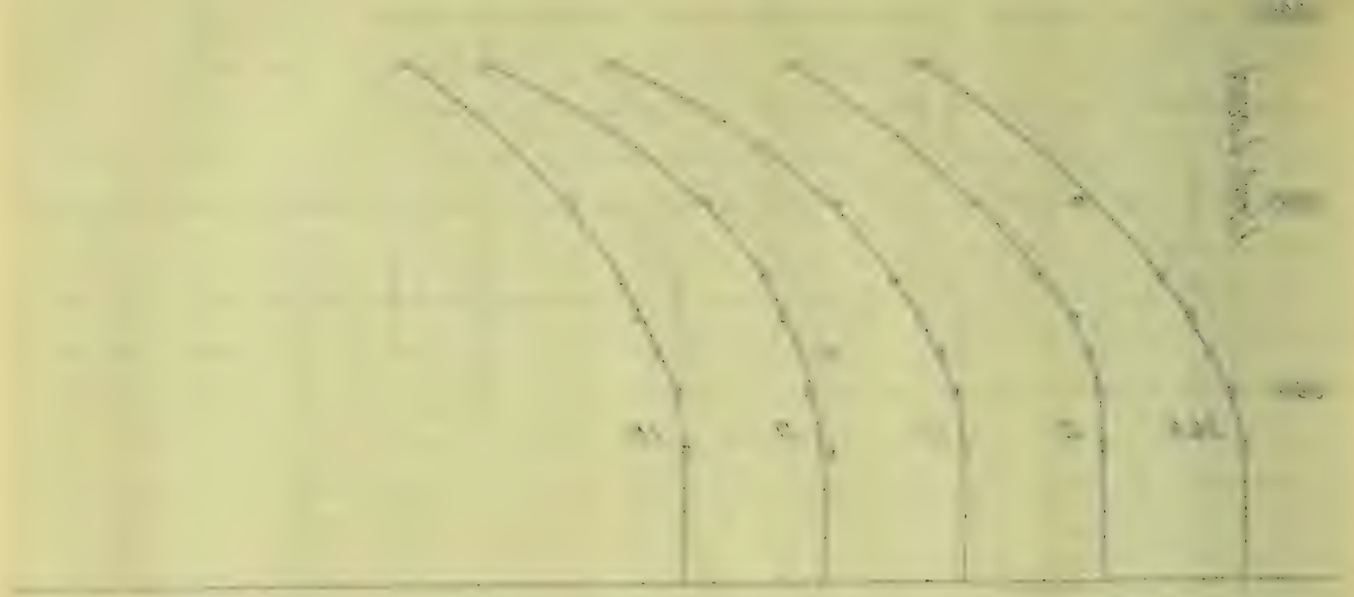




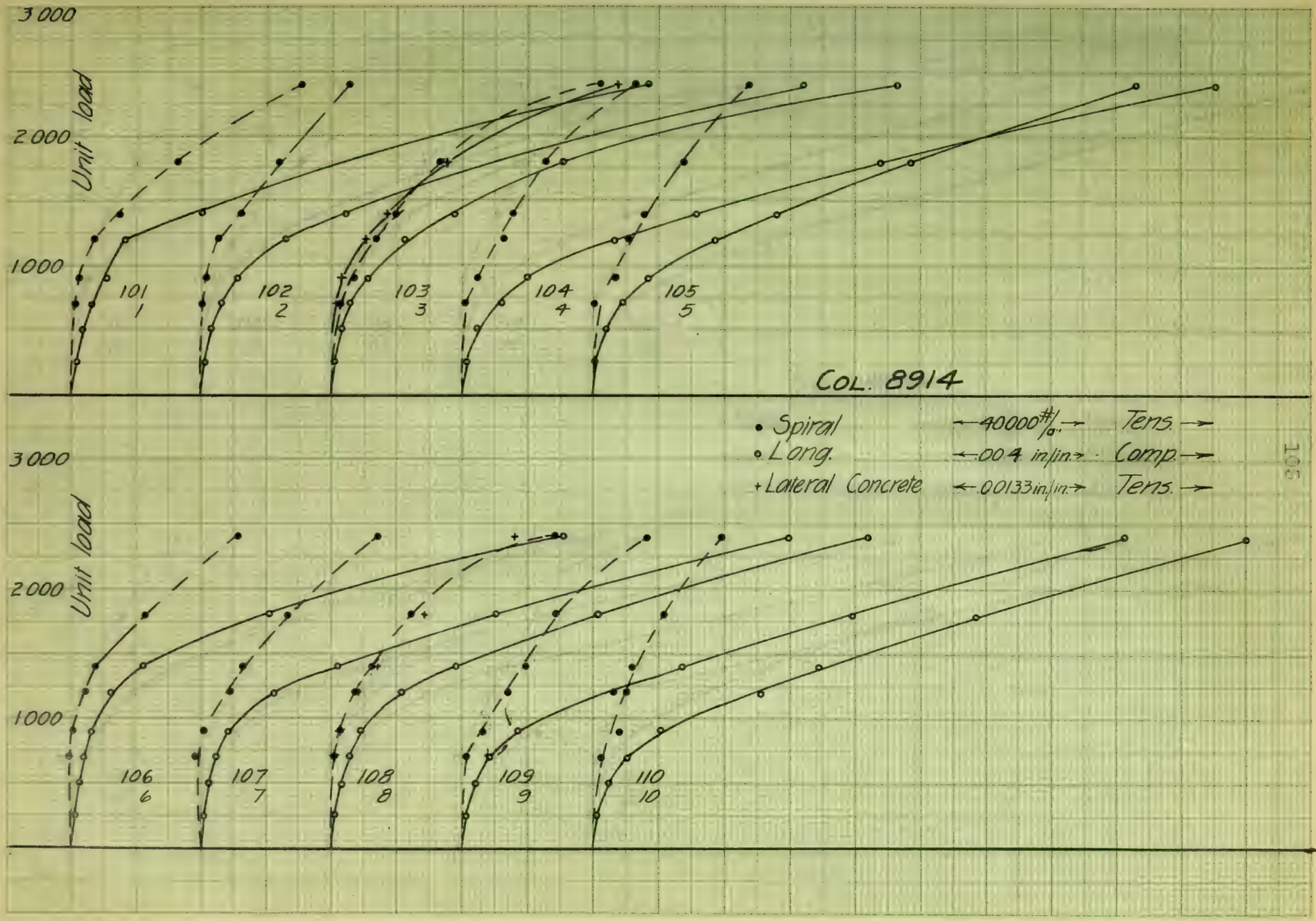
COL. 8913

←40000#/in.→
Tens. →



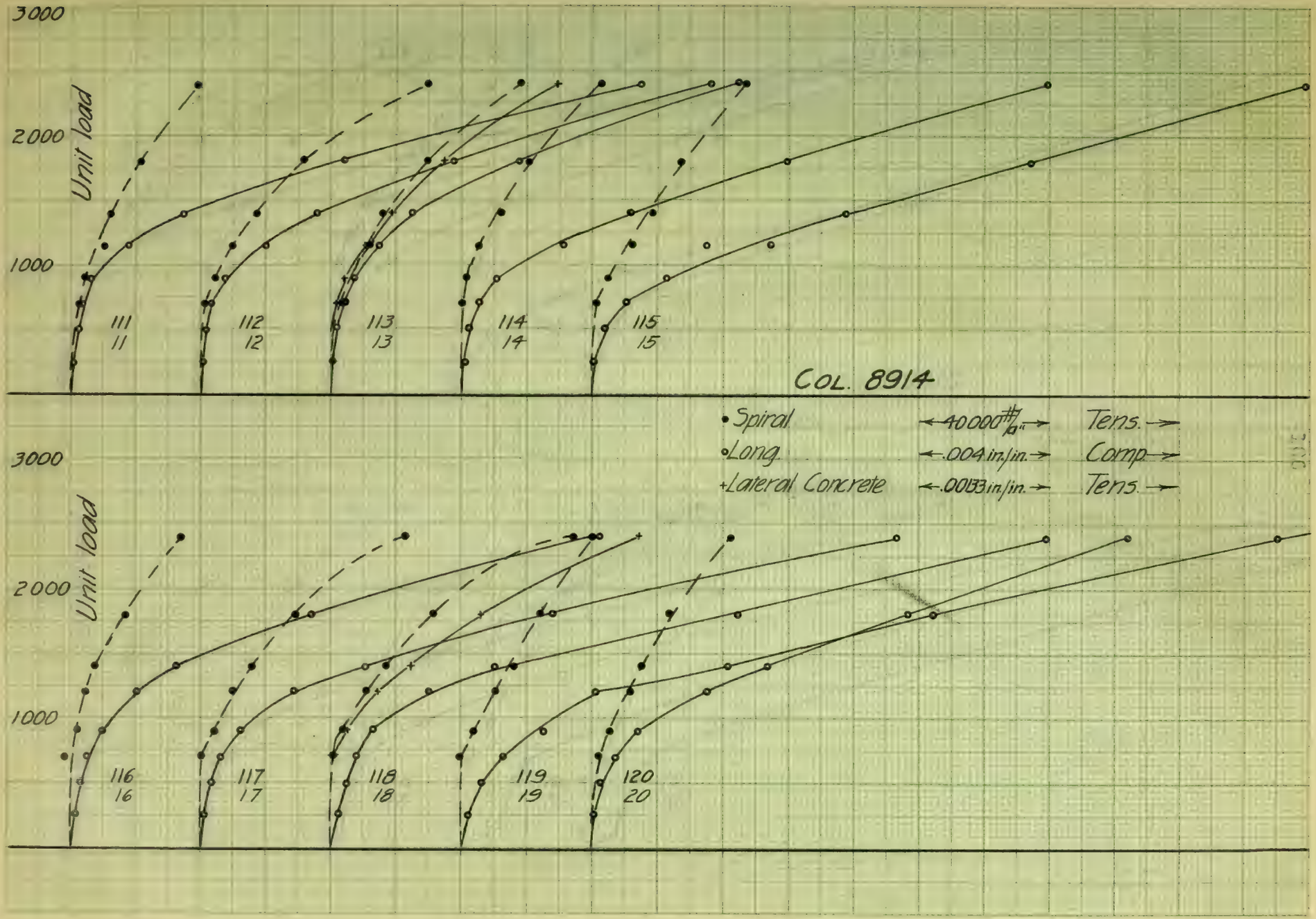




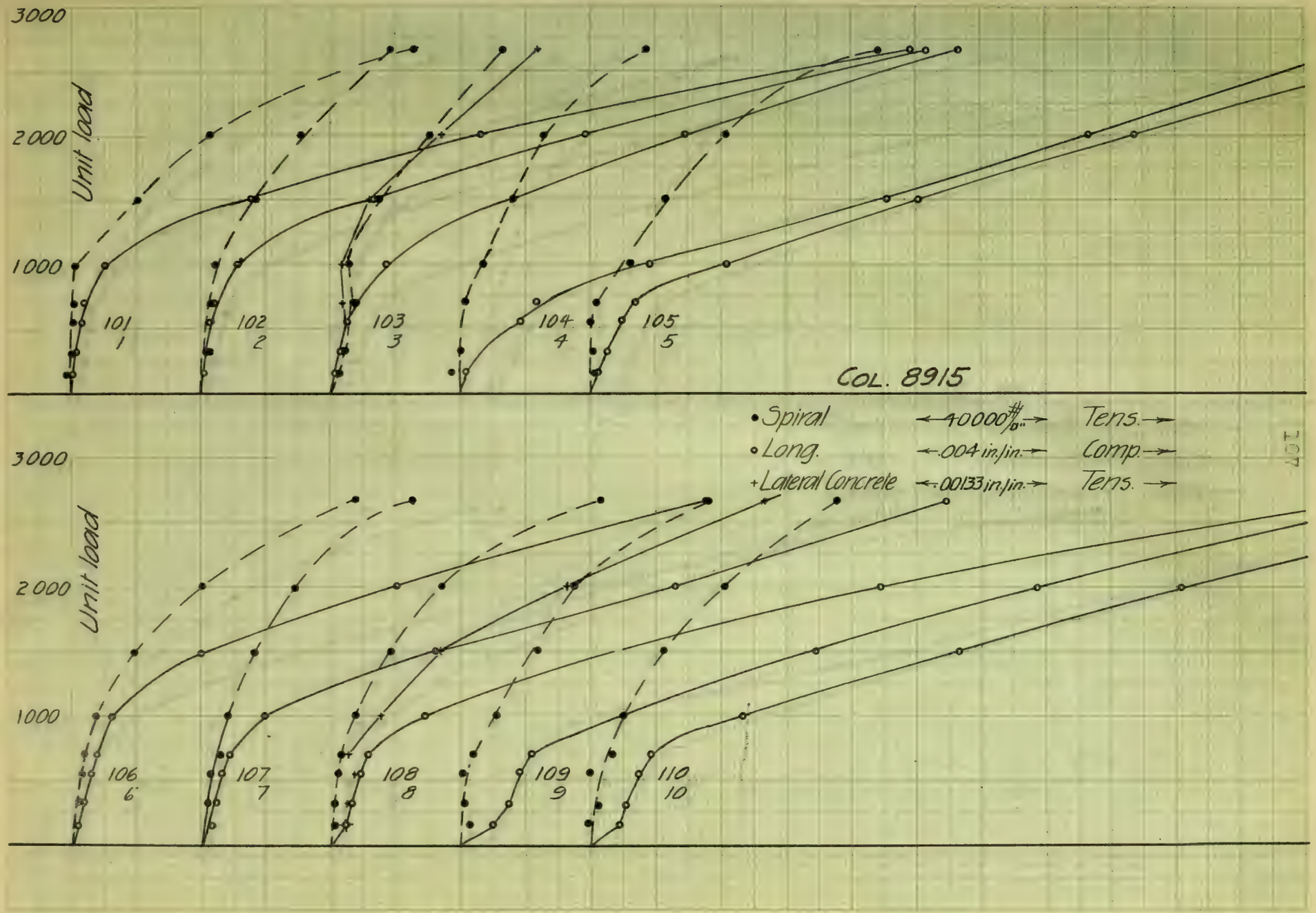

3000
2000
1000
Unit load
101
1
102
2
103
3
104
4
105
5
COL. 8914
• Spiral ← 40000 #/□" → Tens. →
∘ Long. ← .004 in./in. → Comp. →
+ Lateral Concrete ← .00133 in./in. → Tens. →
3000
2000
1000
Unit load
106
6
107
7
108
8
109
9
110
10

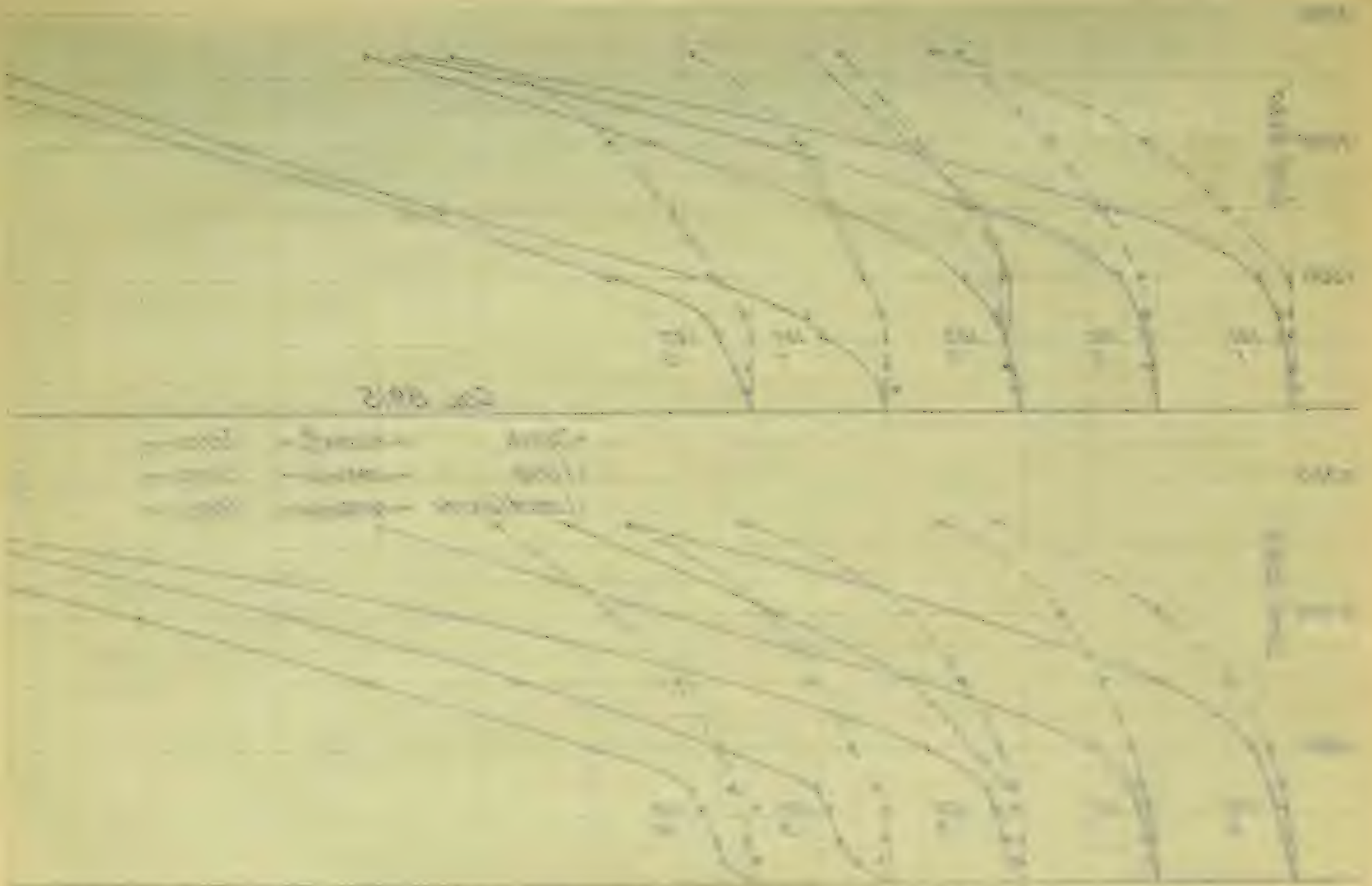


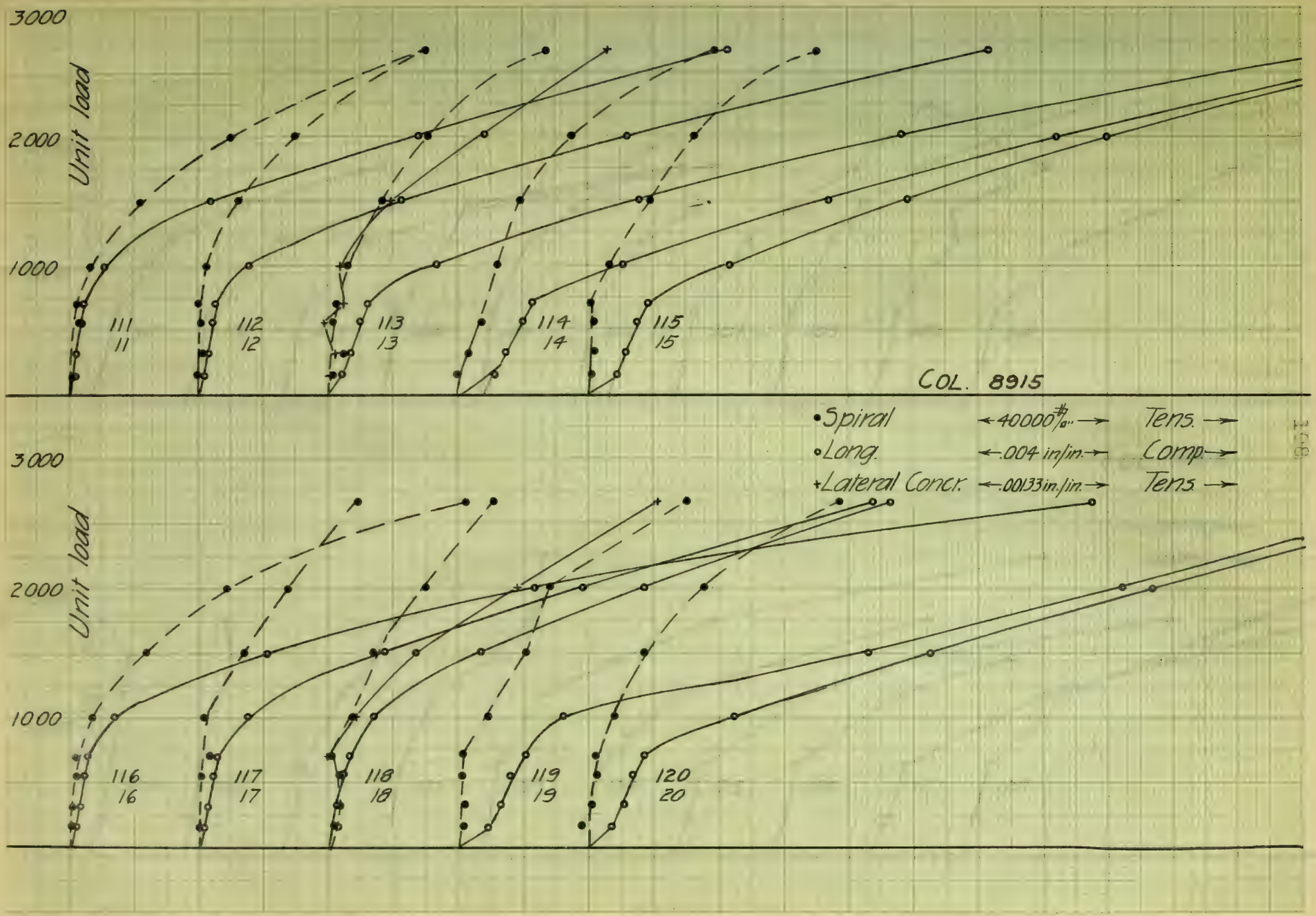



3000
2000
1000
Unit load
111
11
112
12
113
13
114
14
115
15
COL. 8914
• Spiral ← 40000 #/in. → Tens. →
∘ Long. ← .004 in./in. → Comp. →
+ Lateral Concrete ← .00133 in./in. → Tens. →
3000
2000
1000
Unit load
116
16
117
17
118
18
119
19
120
20

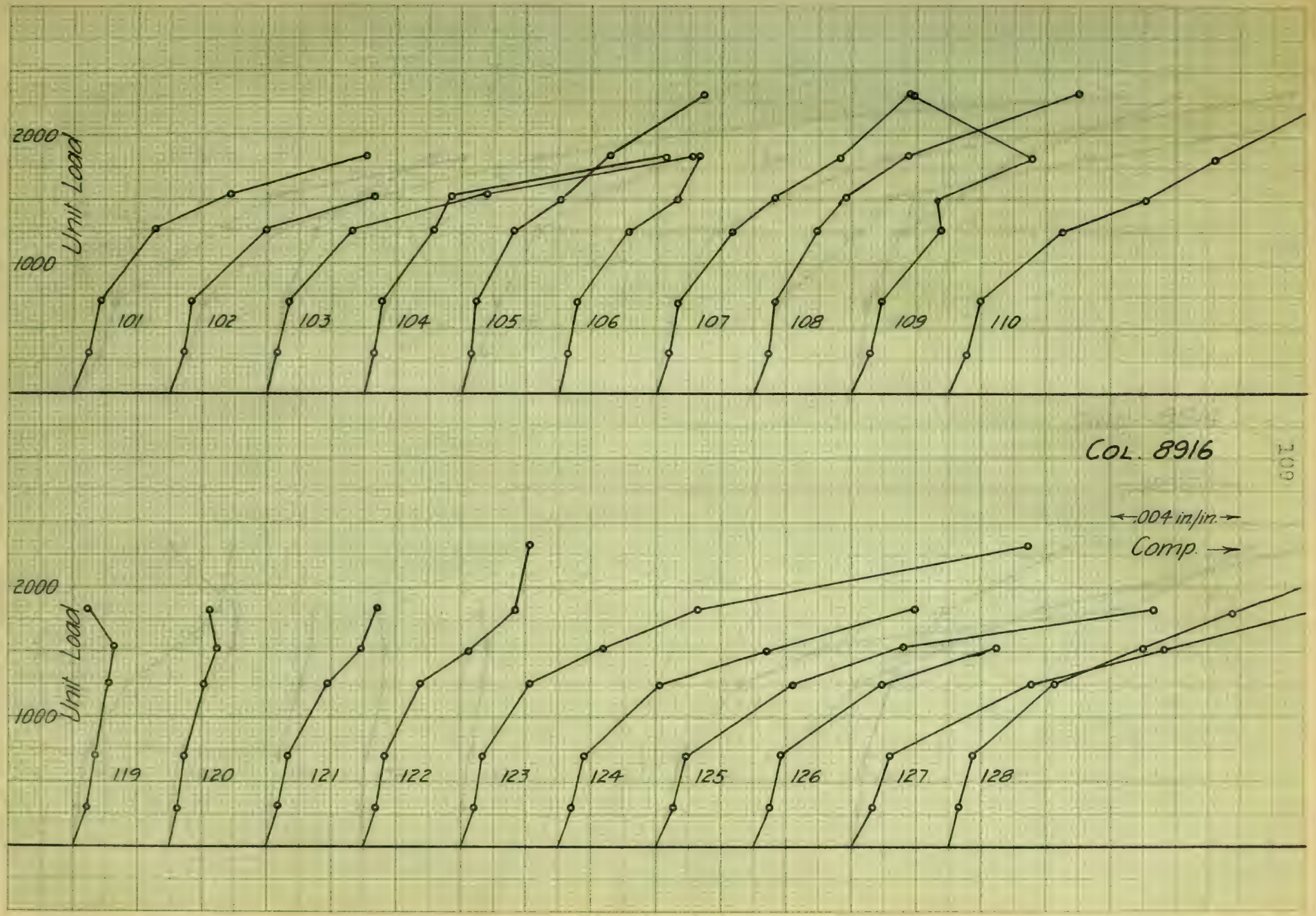



3000
2000
1000
Unit load
101
1
102
2
103
3
104
4
105
5
COL. 8915
• Spiral ← 40000 #/□" → Tens. →
∘ Long. ← .004 in./in. → Comp. →
+ Lateral Concrete ← .00133 in./in. → Tens. →
3000
2000
1000
Unit load
106
6
107
7
108
8
109
9
110
10



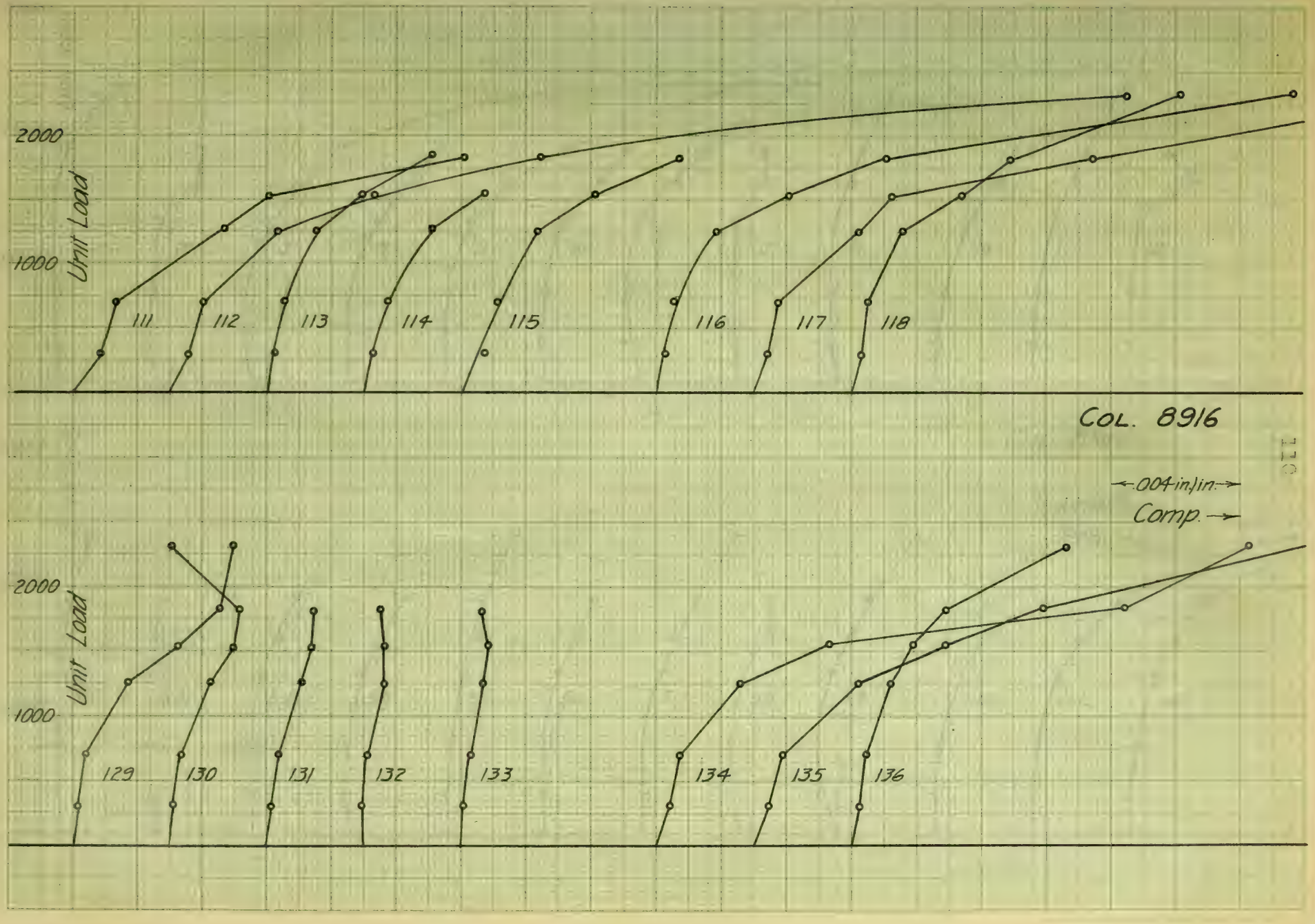

3000
2000
1000
Unit load
111
11
112
12
113
13
114
14
115
15
COL. 8915
•Spiral ←40000#/□"→ Tens.→
◦Long. ←.004 in/in.→ Comp.→
+Lateral Concr. ←.00133 in./in.→ Tens.→
3000
2000
1000
Unit load
116
16
117
17
118
18
119
19
120
20




2000
Unit Load
1000
101
102
103
104
105
106
107
108
109
110
COL. 8916
209
.004 in./in.
Comp.
2000
Unit Load
1000
119
120
121
122
123
124
125
126
127
128

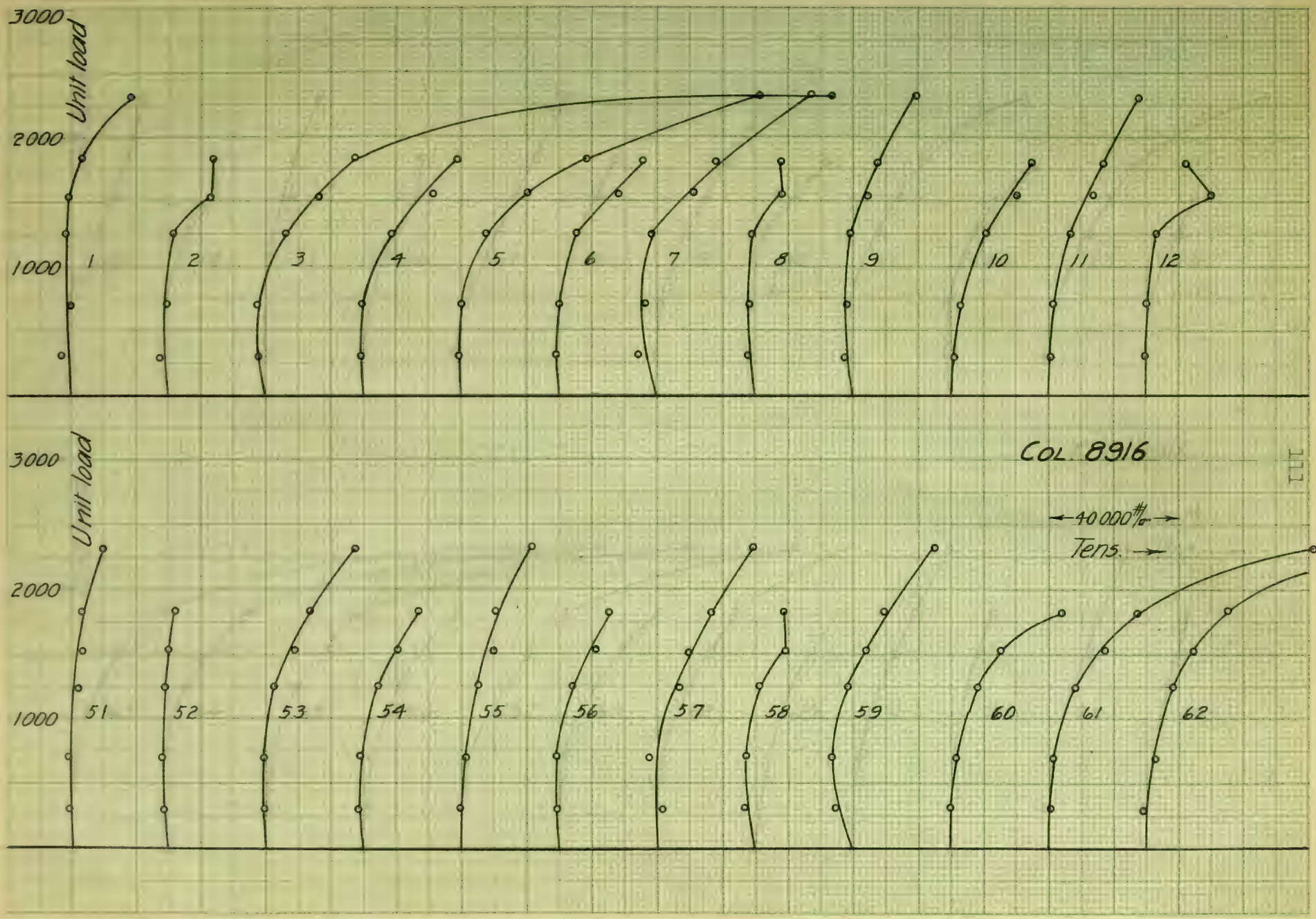


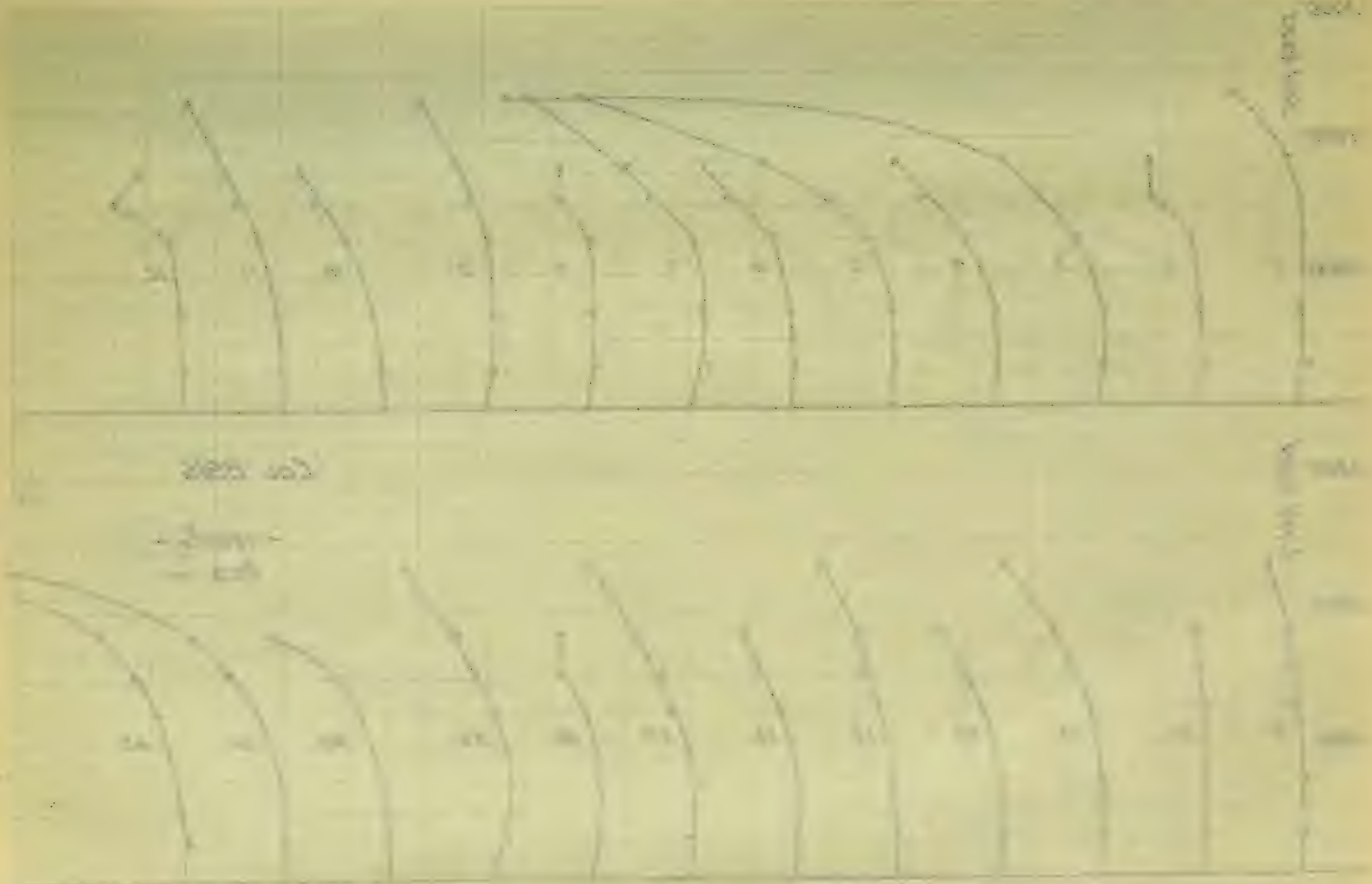


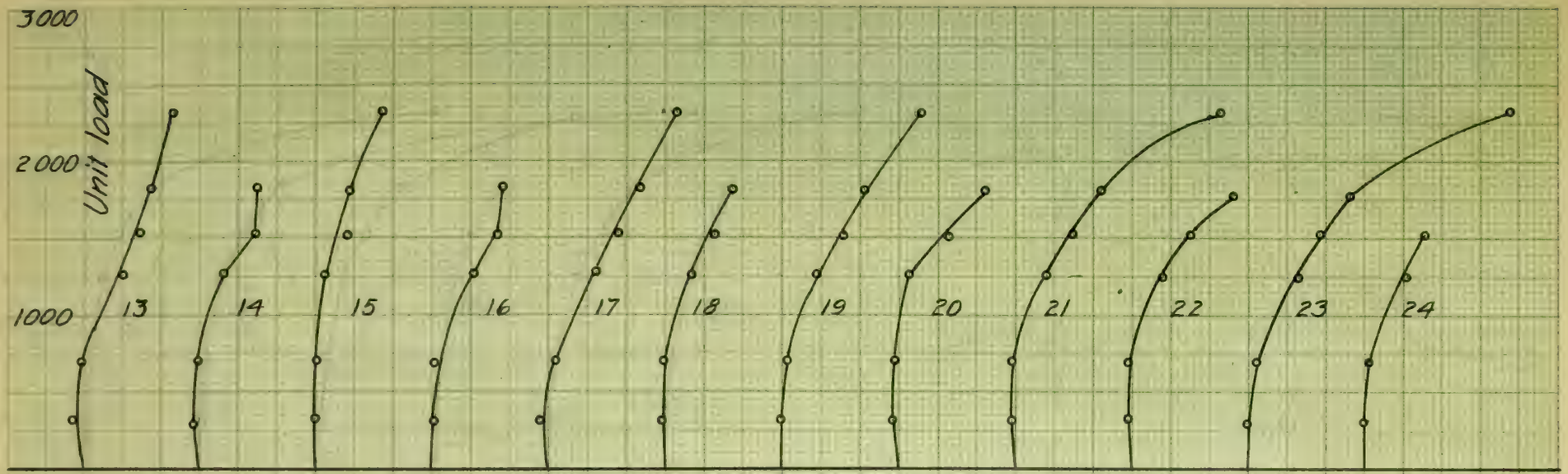

2000
1000
Unit Load
111
112
113
114
115
116
117
118
COL. 8916
.004 in./in.
Comp.
2000
1000
Unit Load
129
130
131
132
133
134
135
136

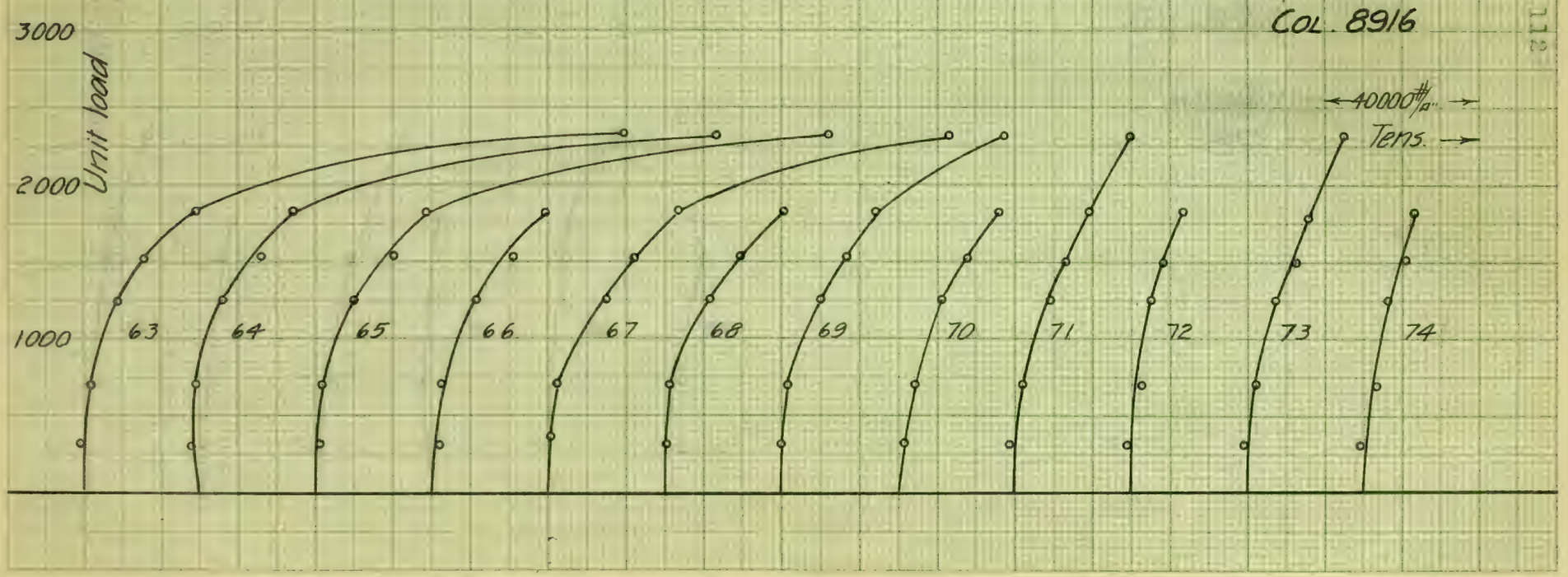





3000
Unit load
2000
1000
1
2
3
4
5
6
7
8
9
10
11
12
3000
Unit load
2000
1000
51
52
53
54
55
56
57
58
59
60
61
62
COL. 8916
40 000 #/in.
Tens.







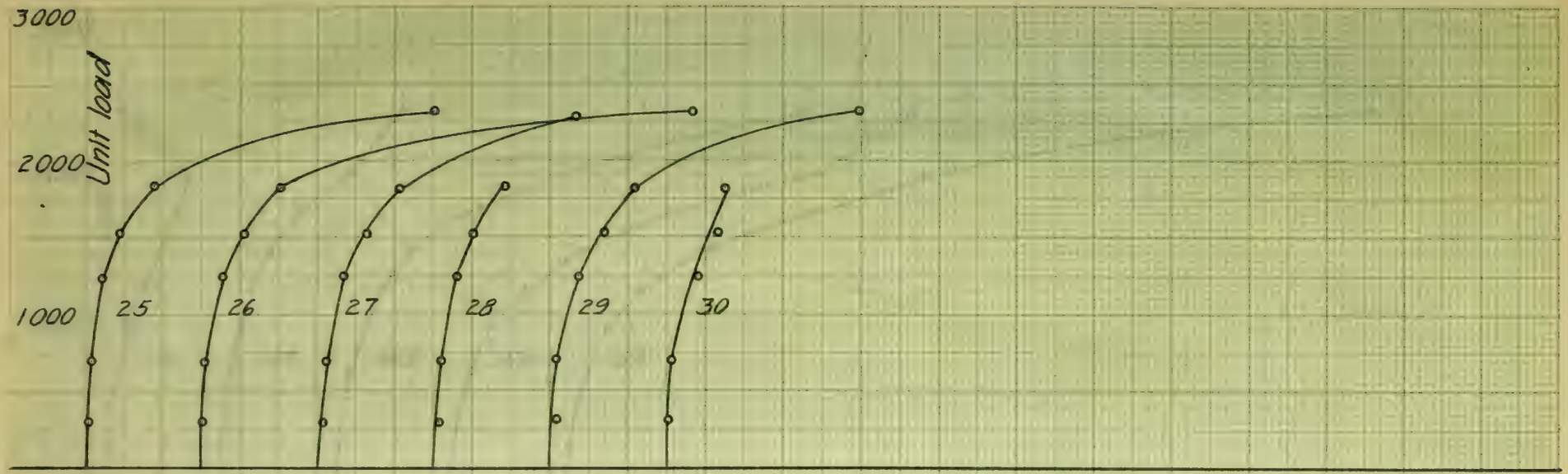
COL. 8916

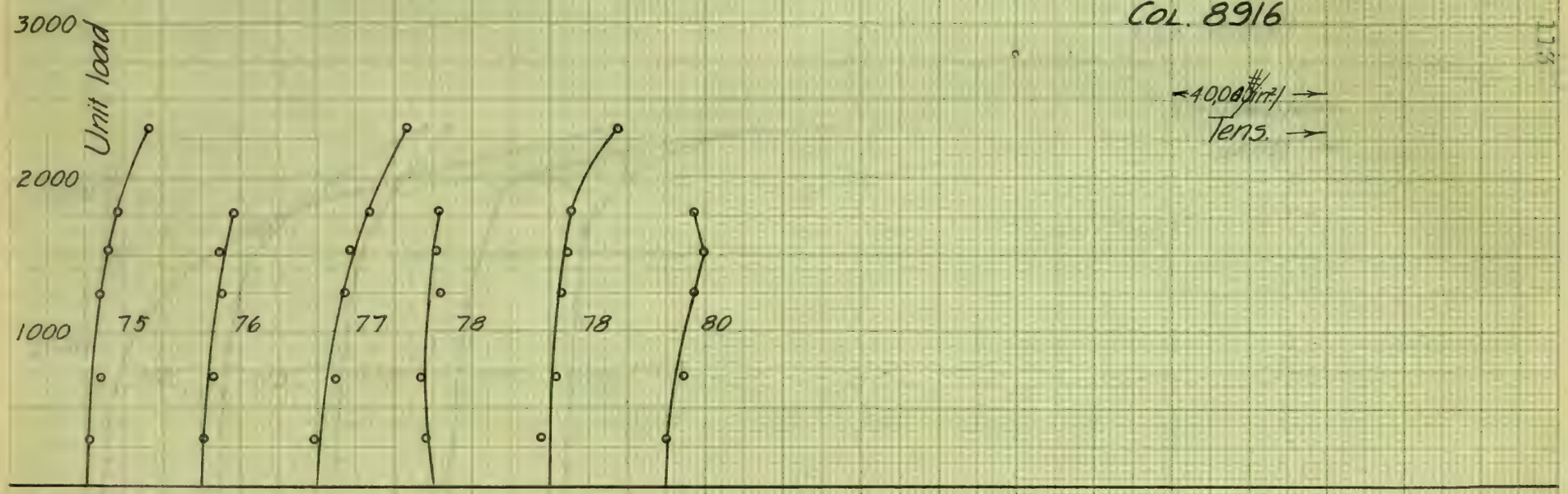
←40000#/□" →

Tens. →

112





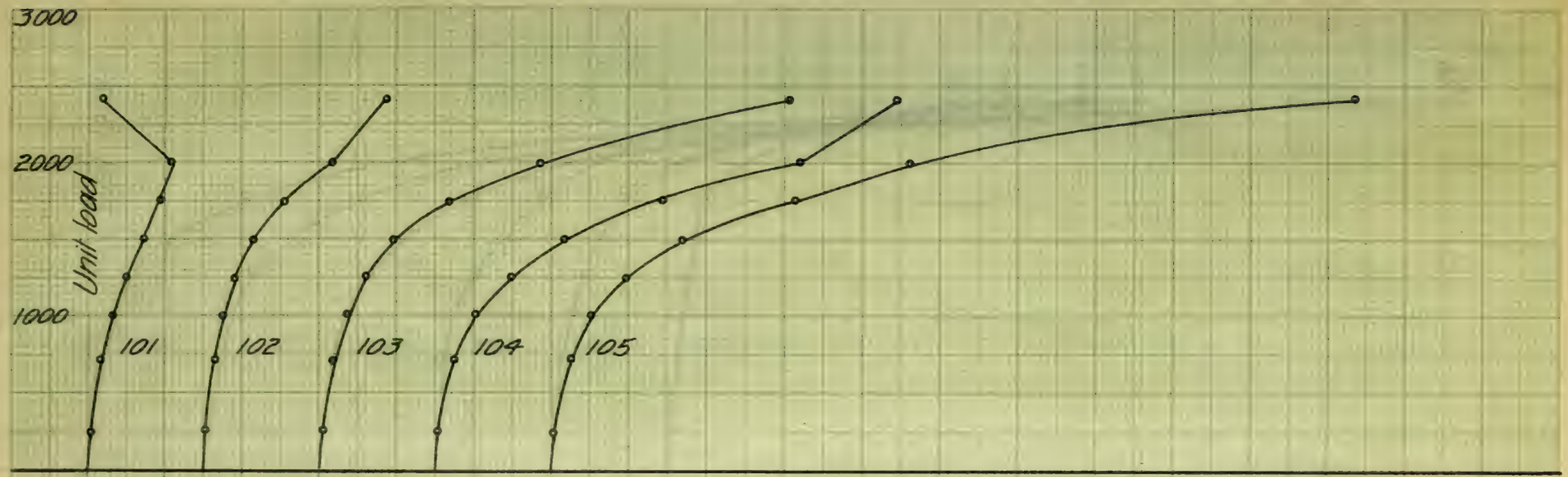


COL. 8916

←40,000#/in.²→
Tens. →

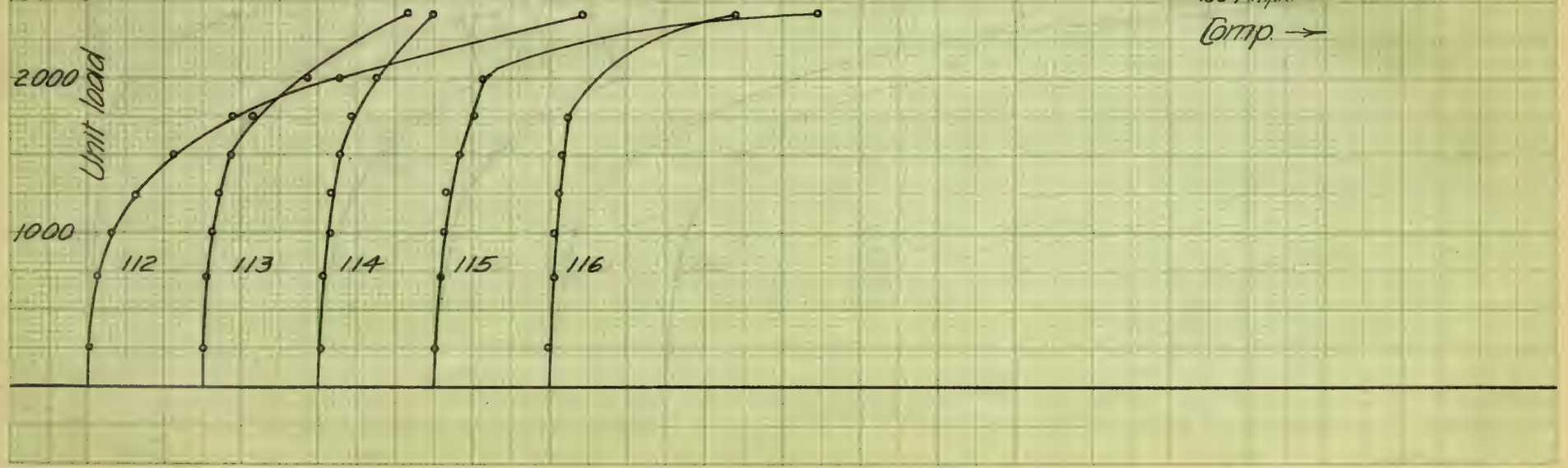




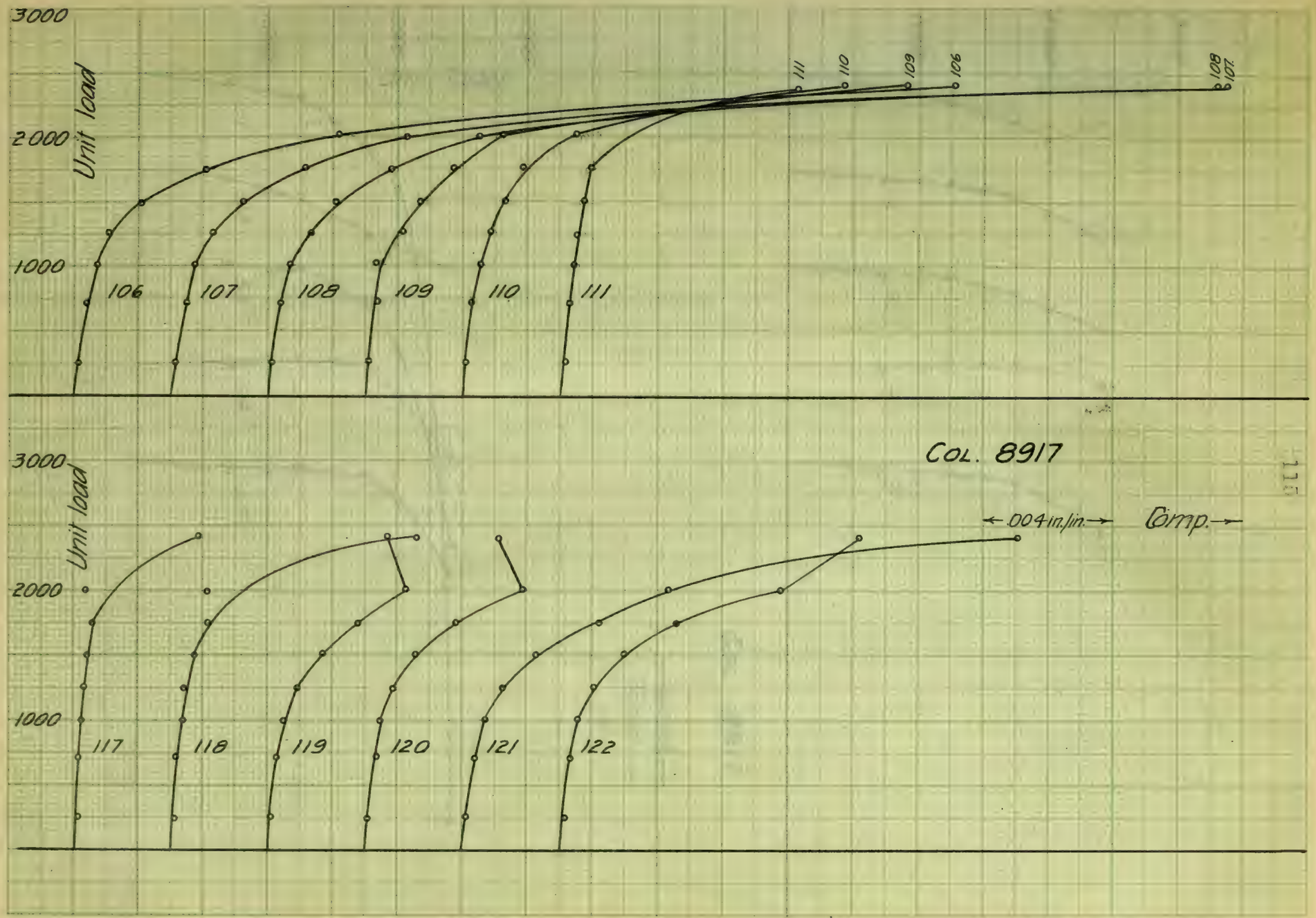


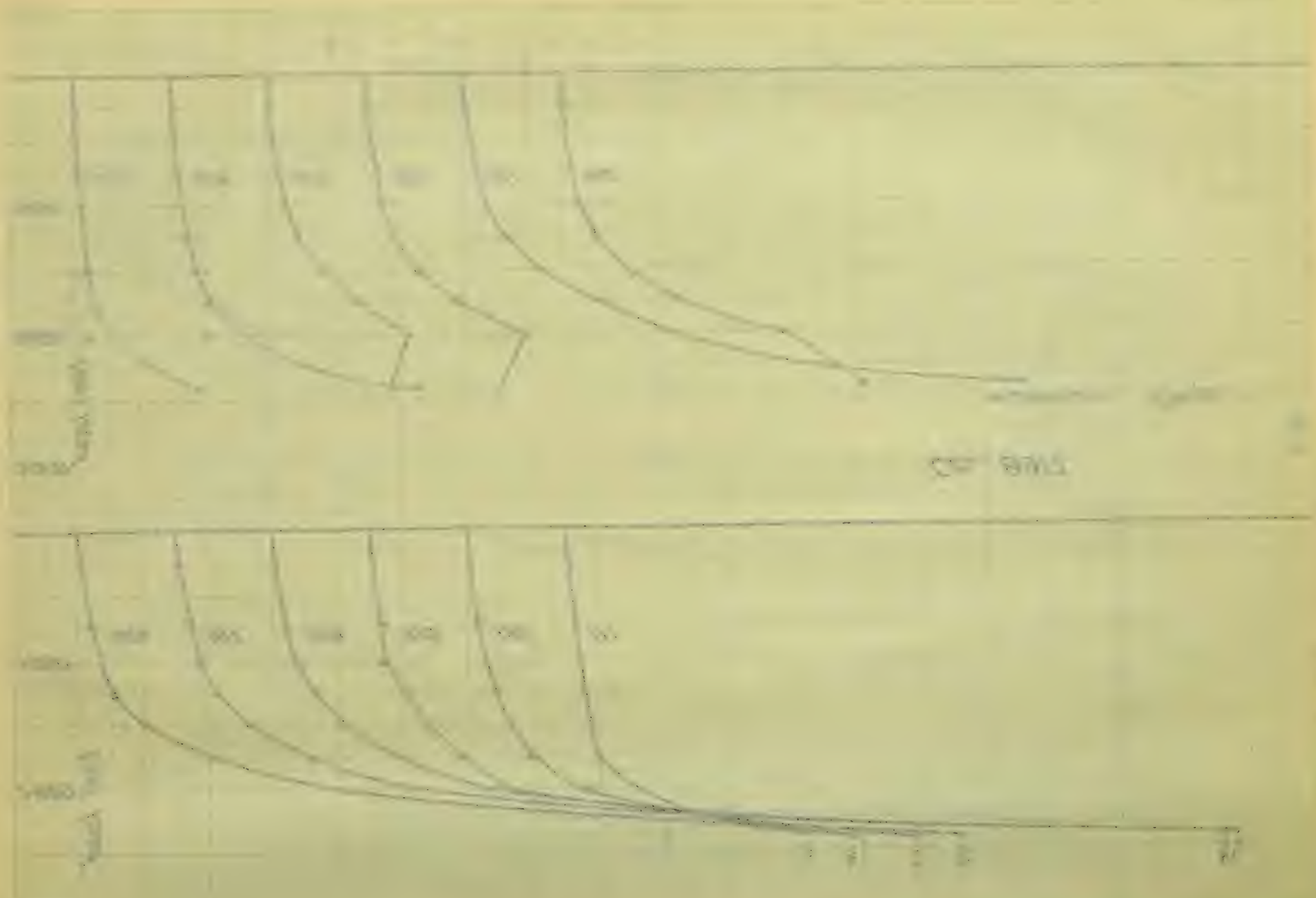
COL. 8917

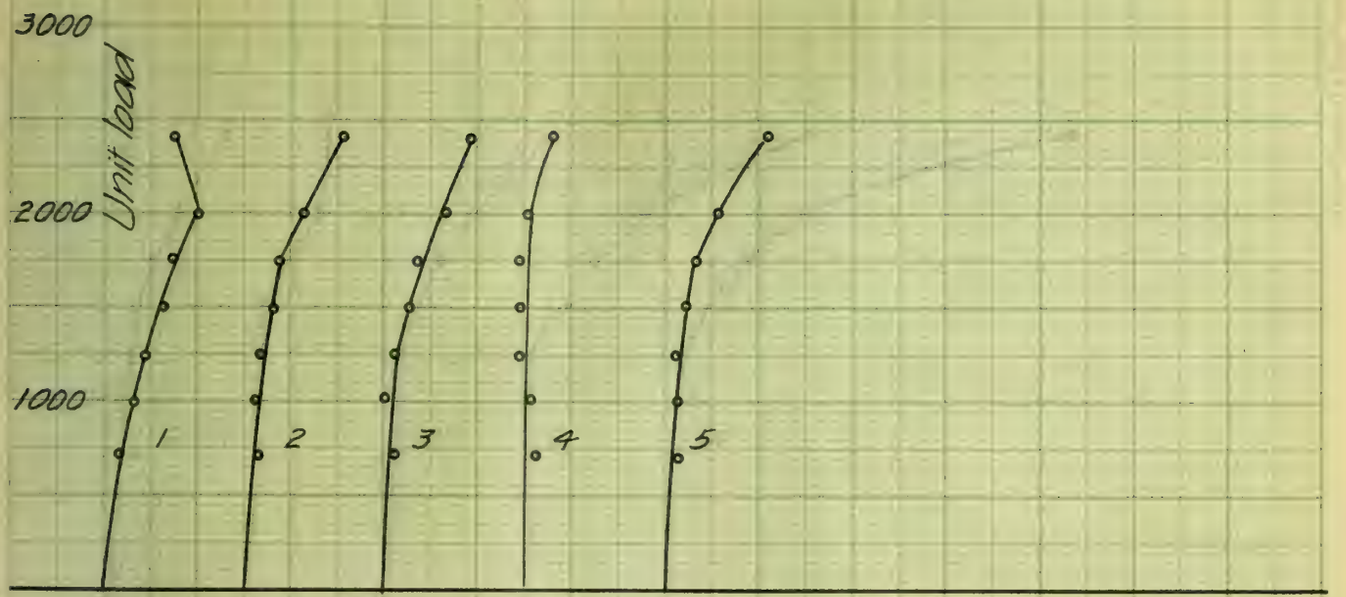
←.004 in./in.→
Comp. →





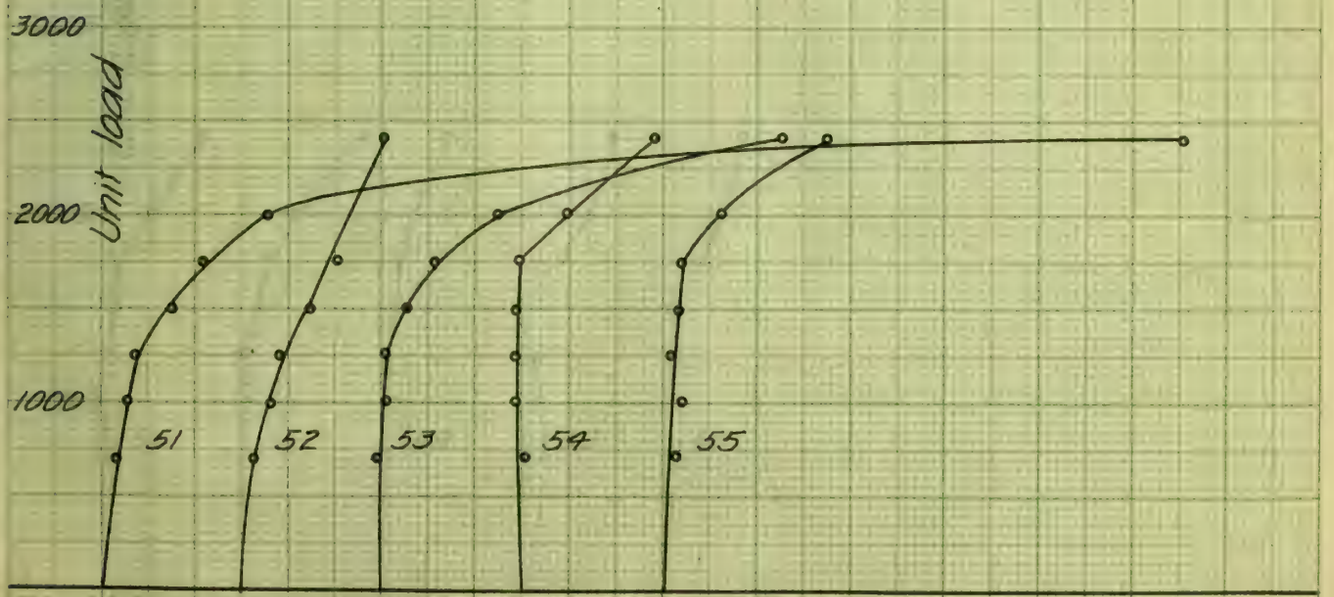

3000
2000
1000
Unit load
106
107
108
109
110
111
111
110
109
106
108
107
3000
2000
1000
Unit load
117
118
119
120
121
122
COL. 8917
←.004 in./in.→ Comp.→

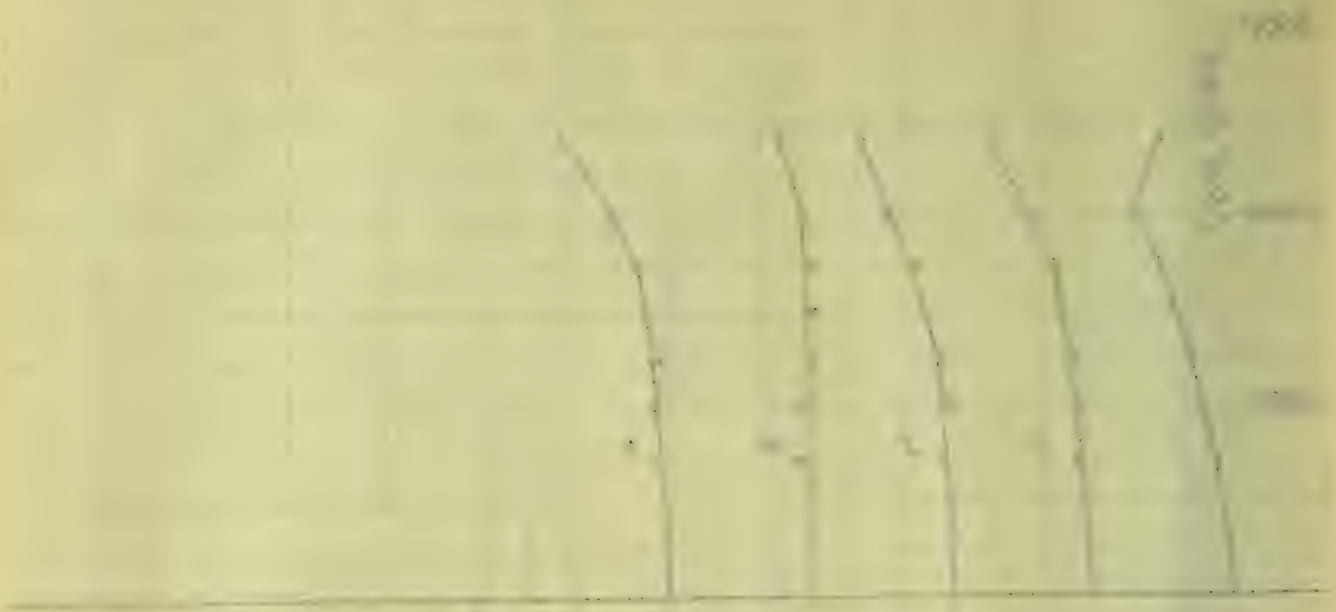


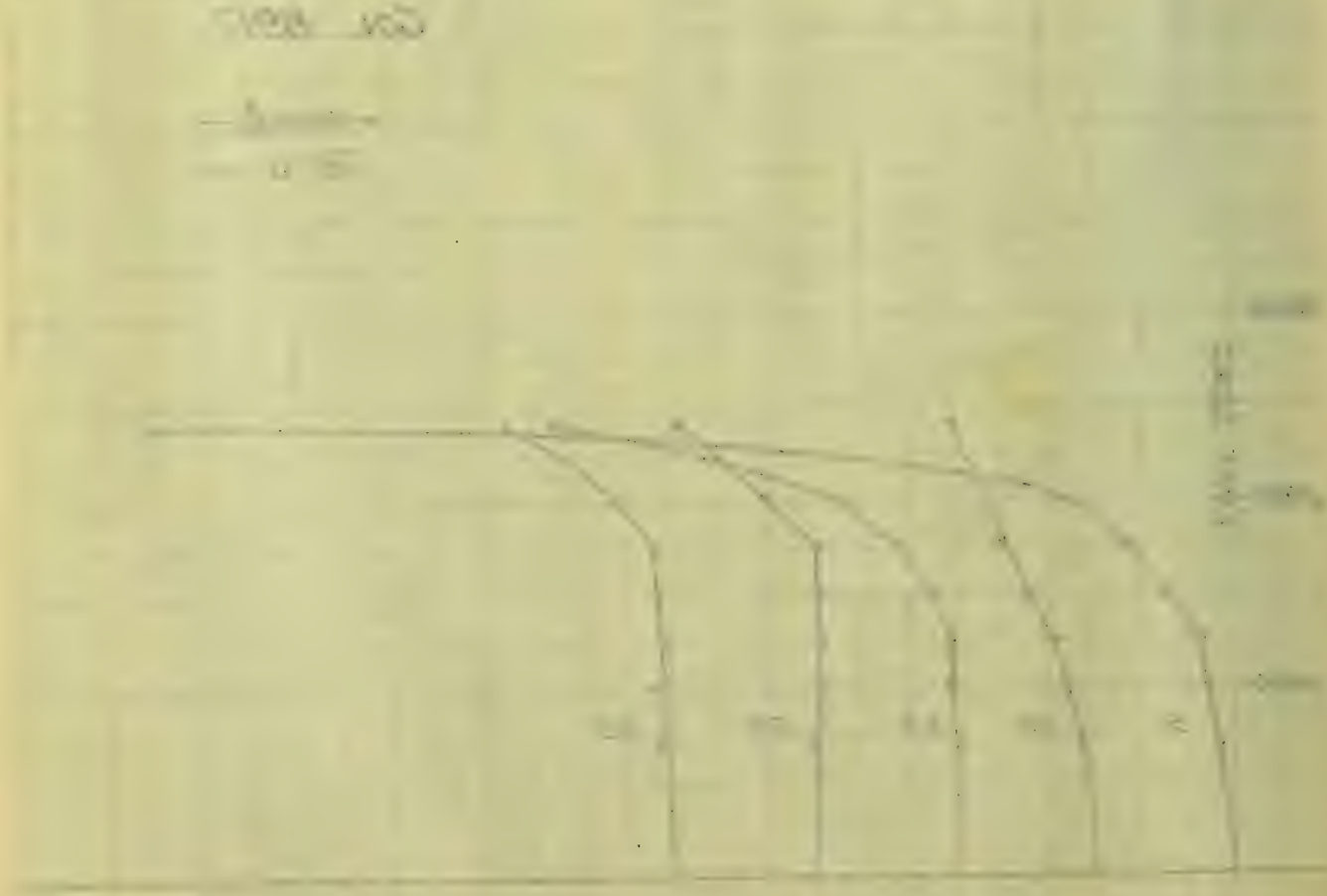


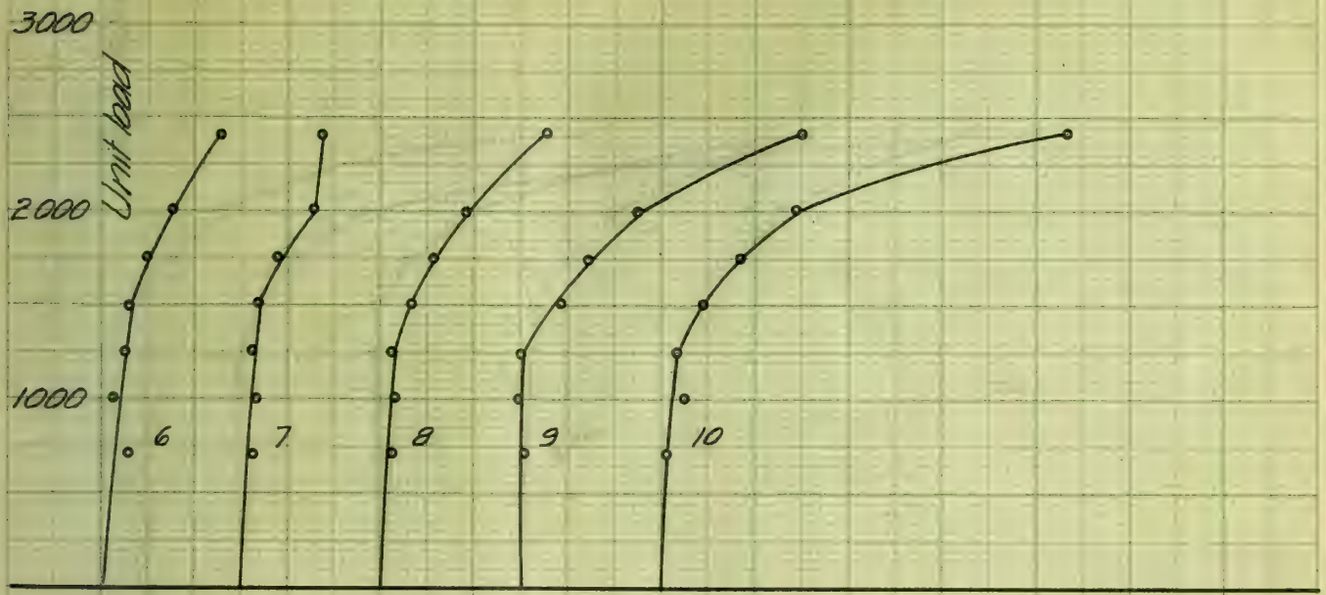
COL. 8917

←40000#/in→
Tens →



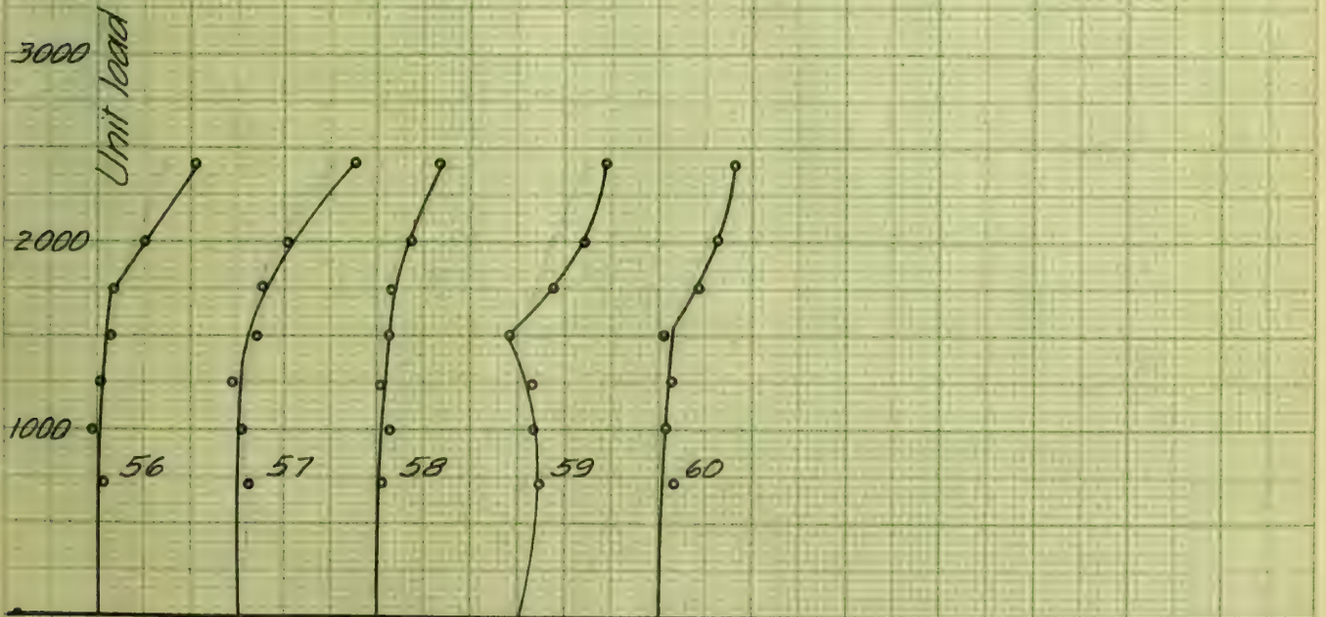






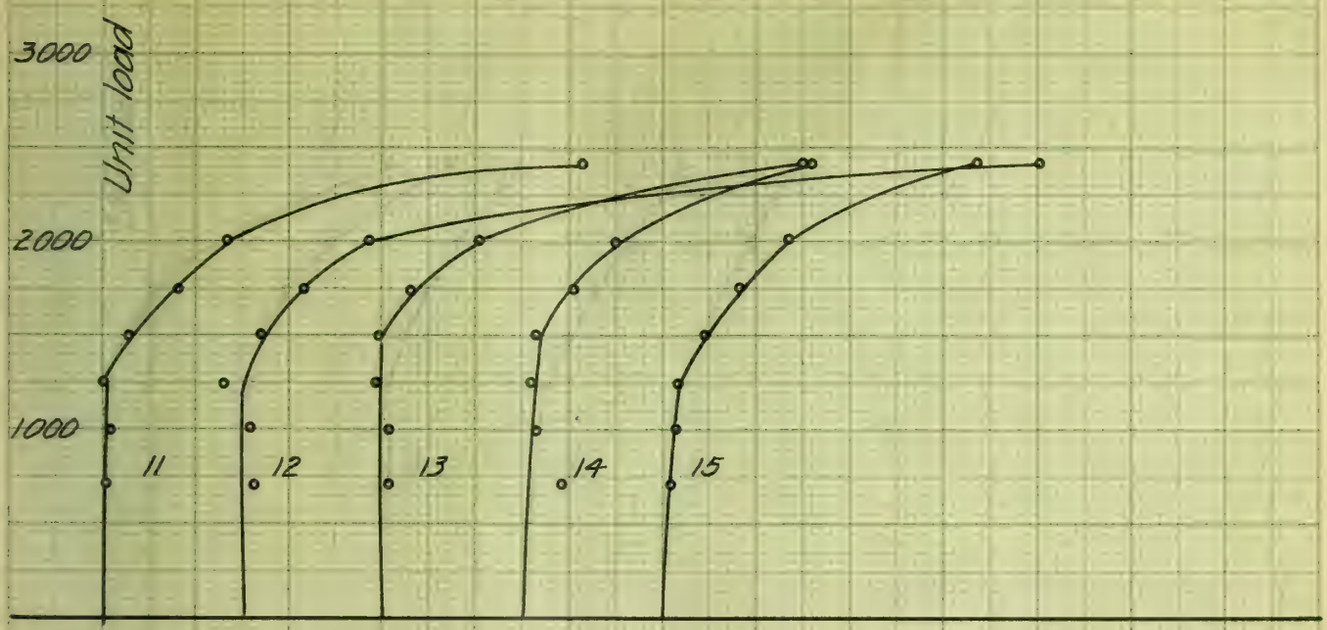
COL. 8917

←40000#/in→
Tens. →



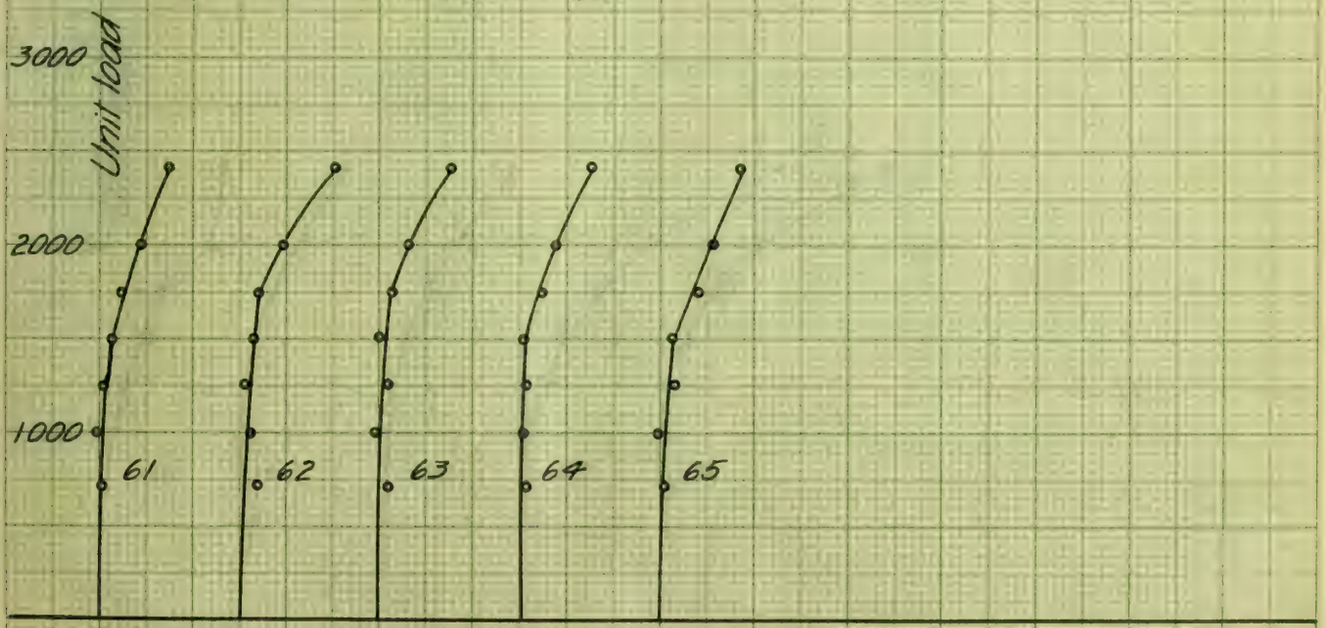


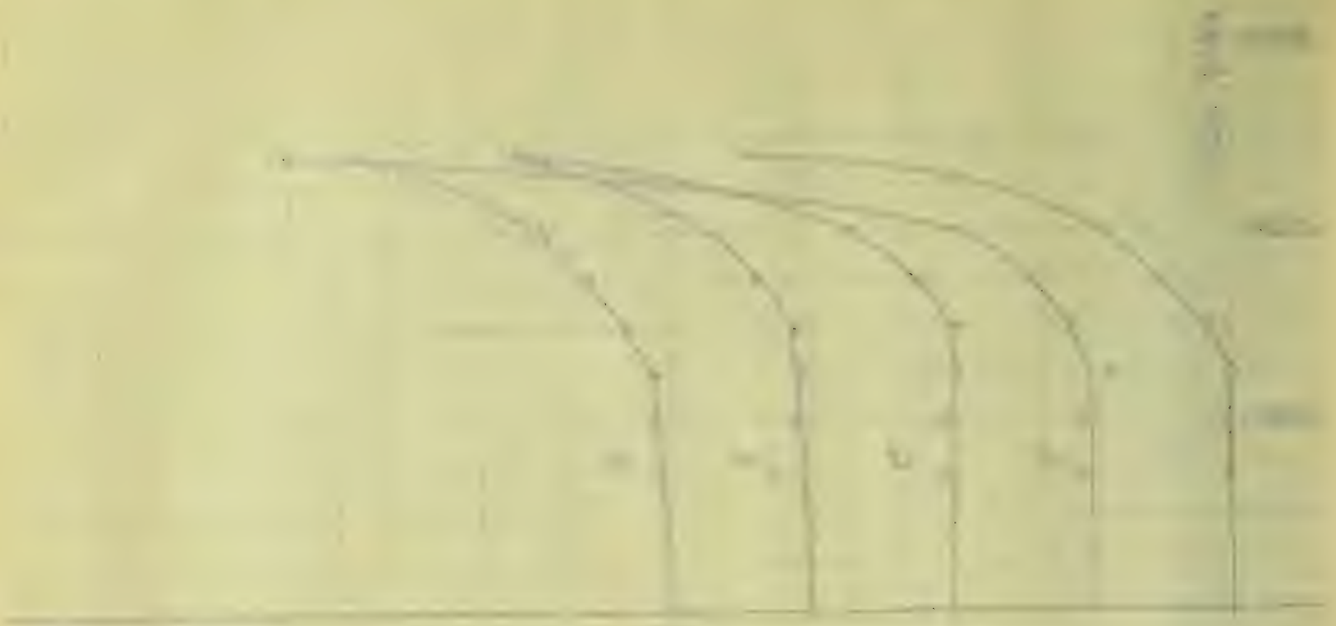


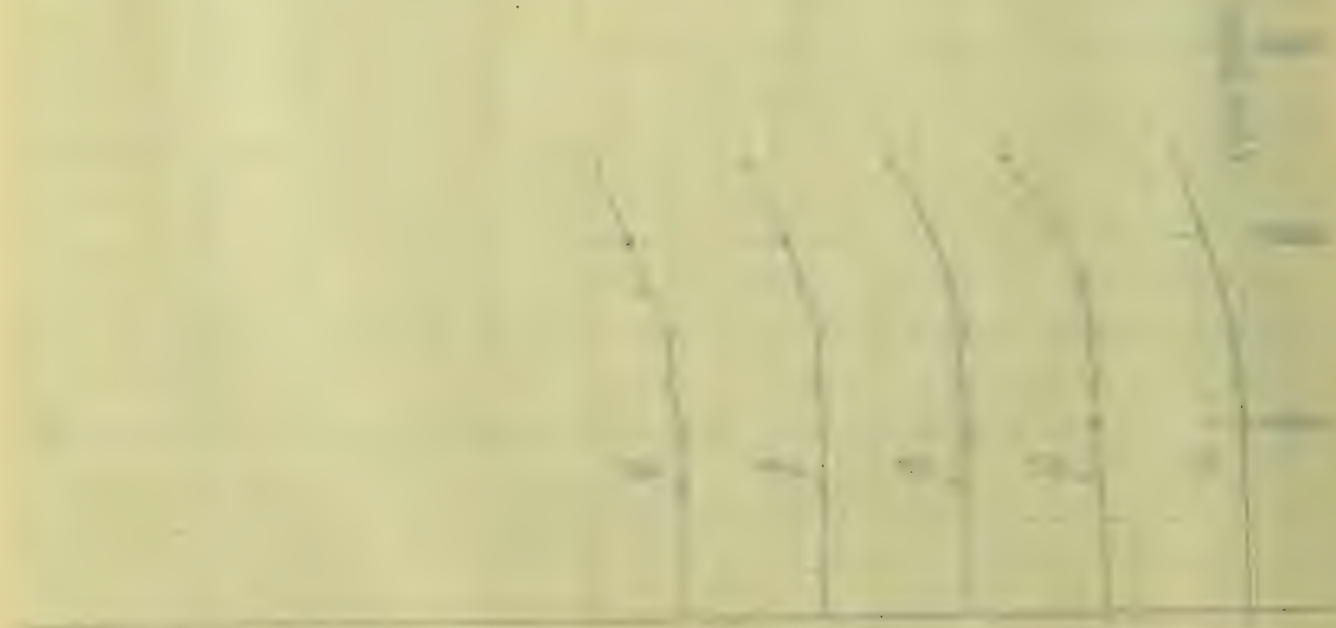


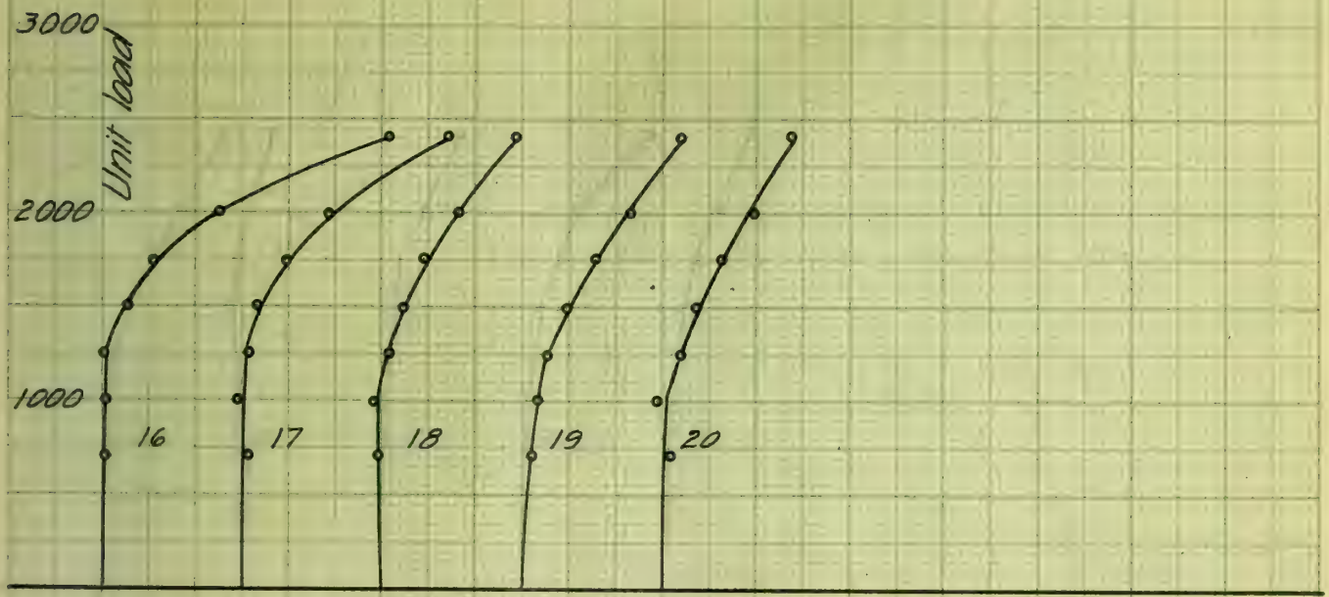
Col. 8917

←40000#/□"→
Tens. →





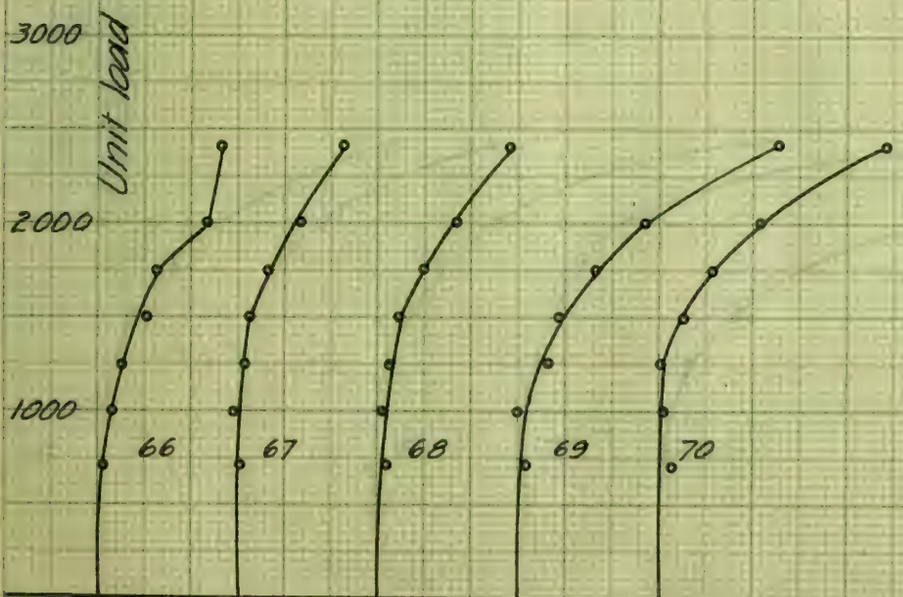




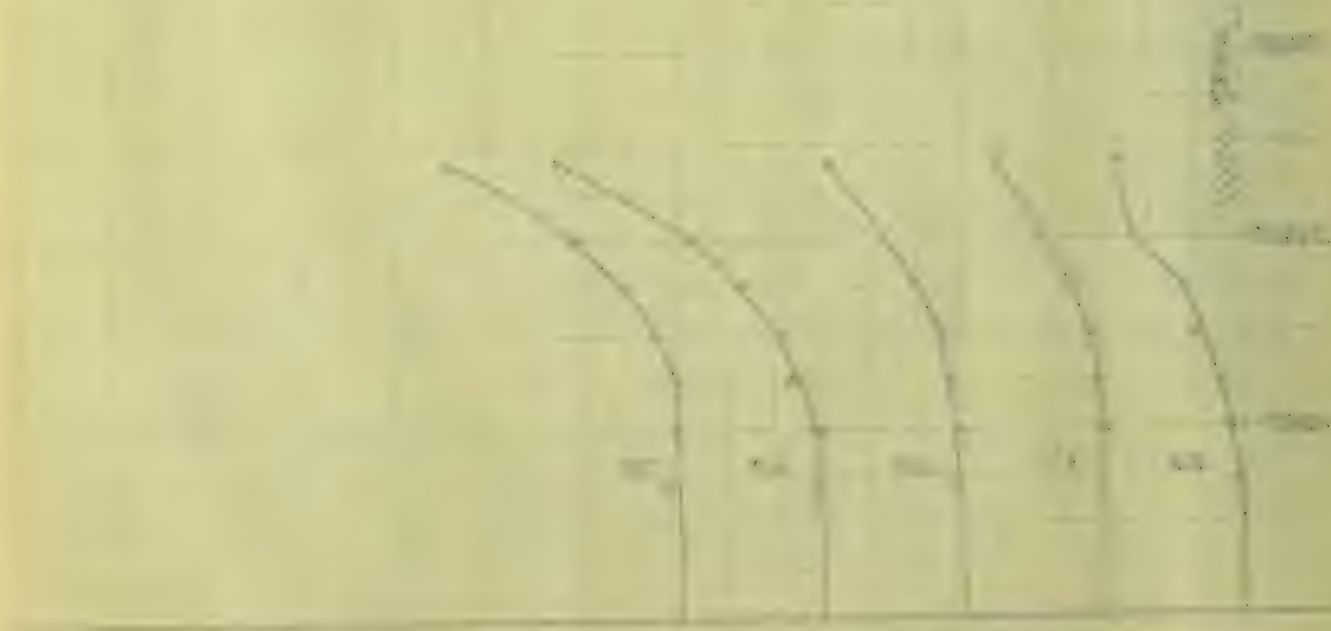
COL. 8917

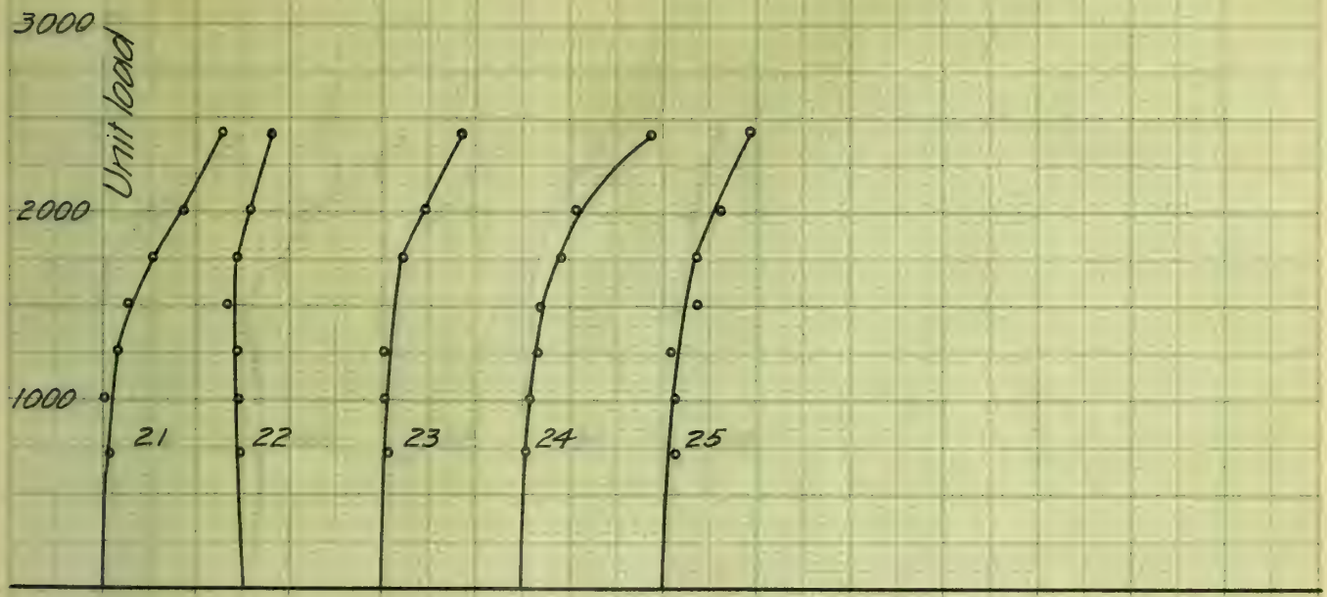
←40000#/in→

Tens. →



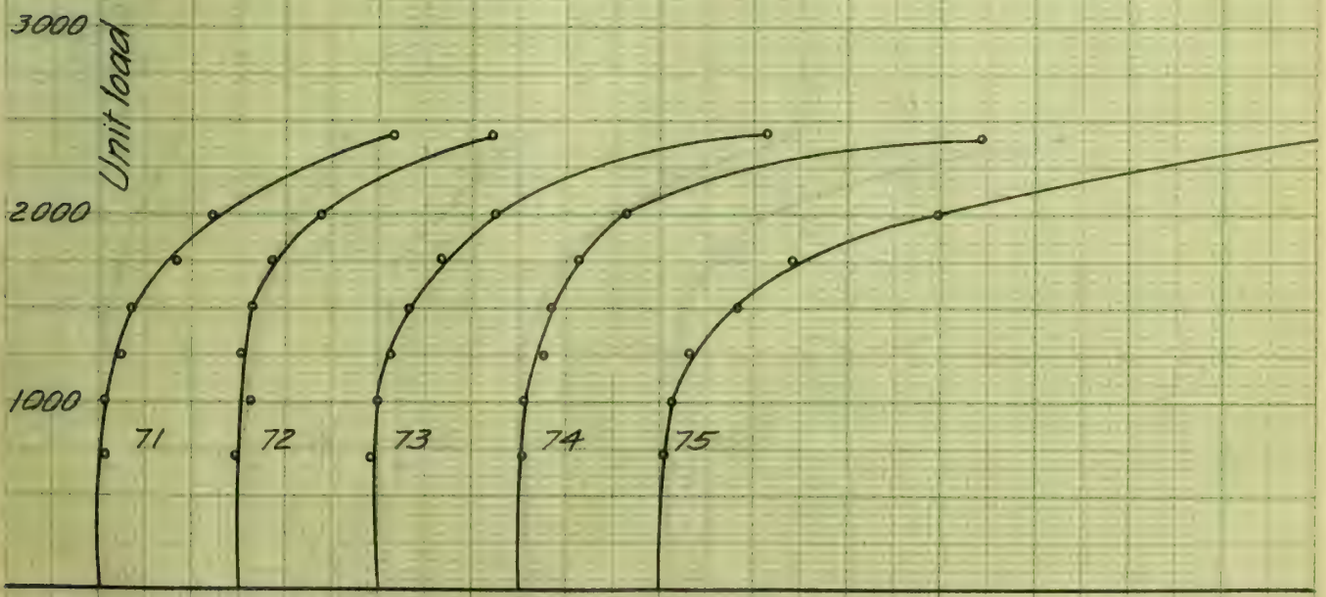






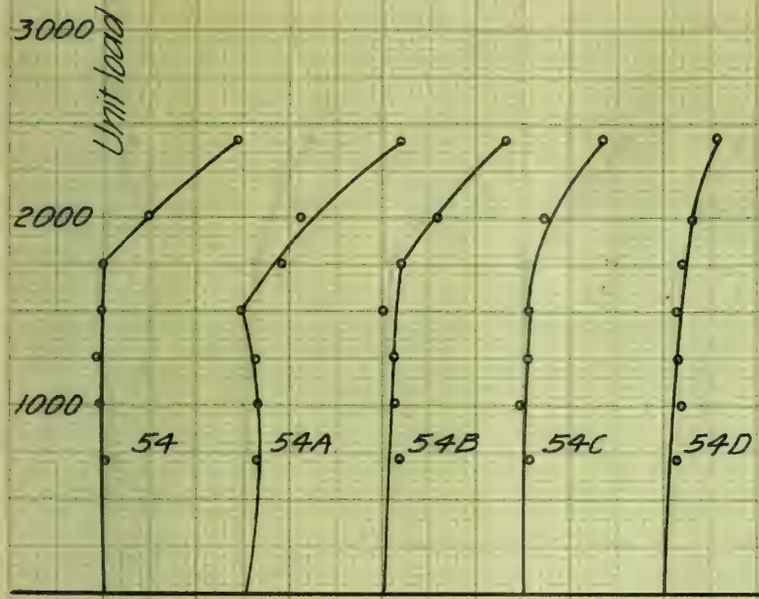
Col. 8917

←40000#/in→
Tens. →



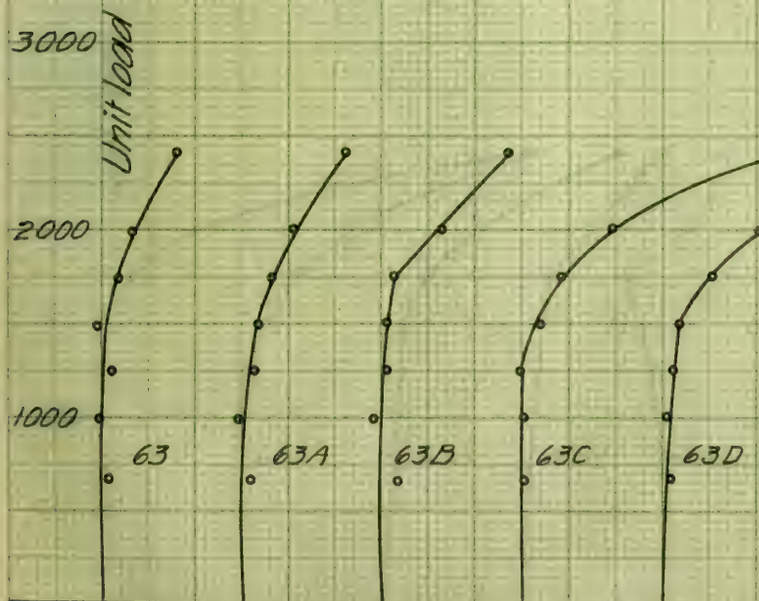






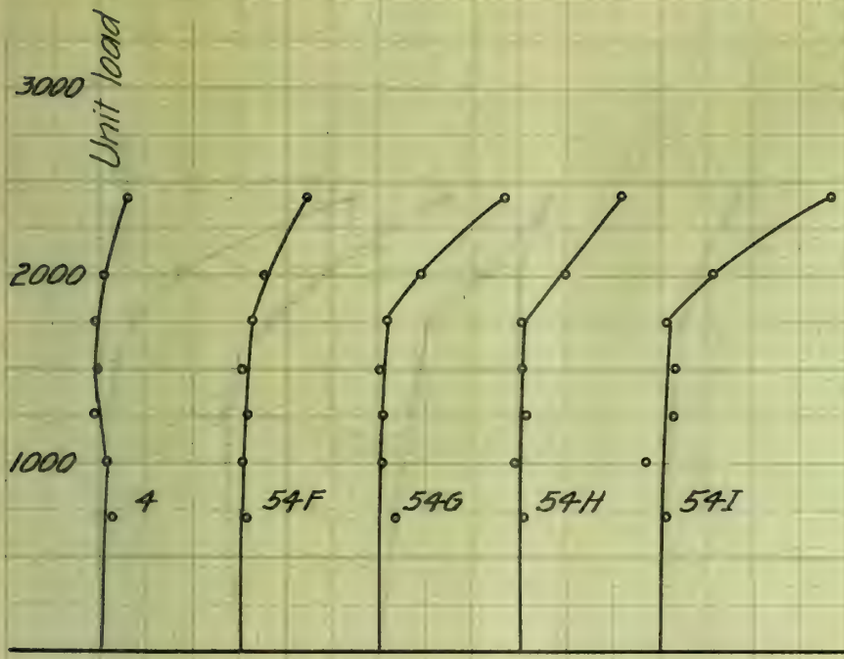
COL. 8917

←40000#/in.→
Tens. →





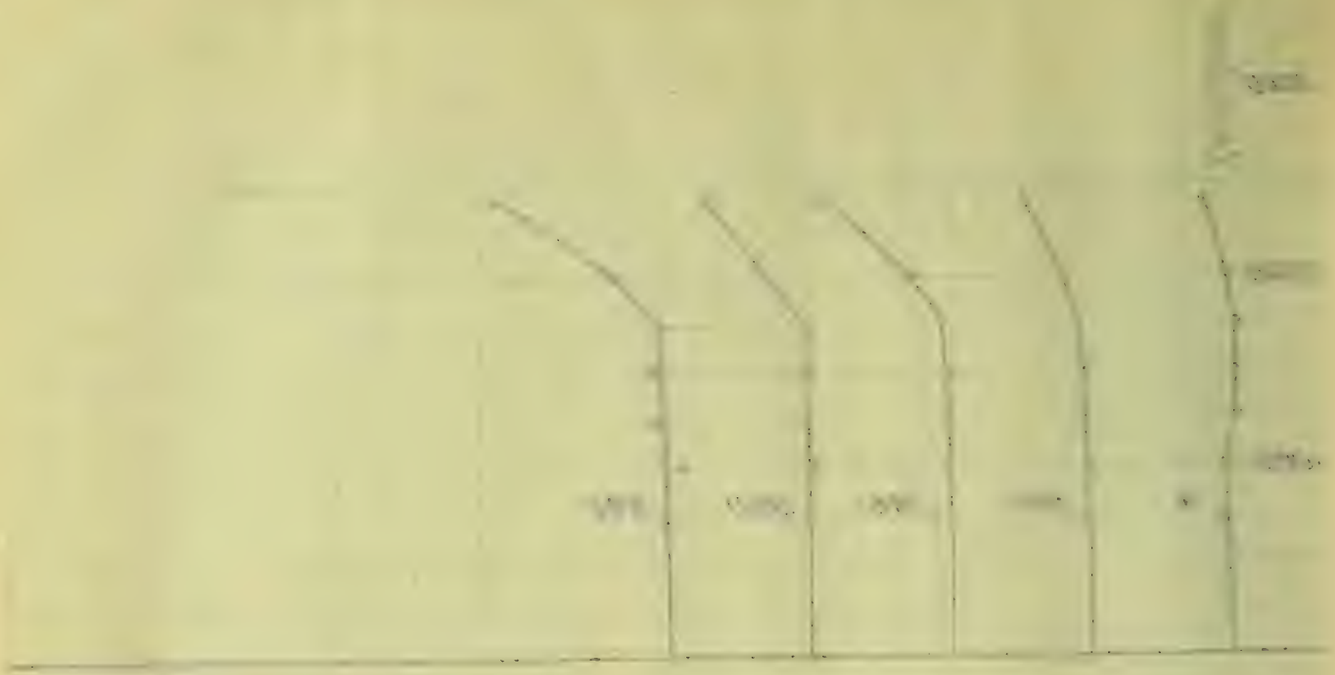


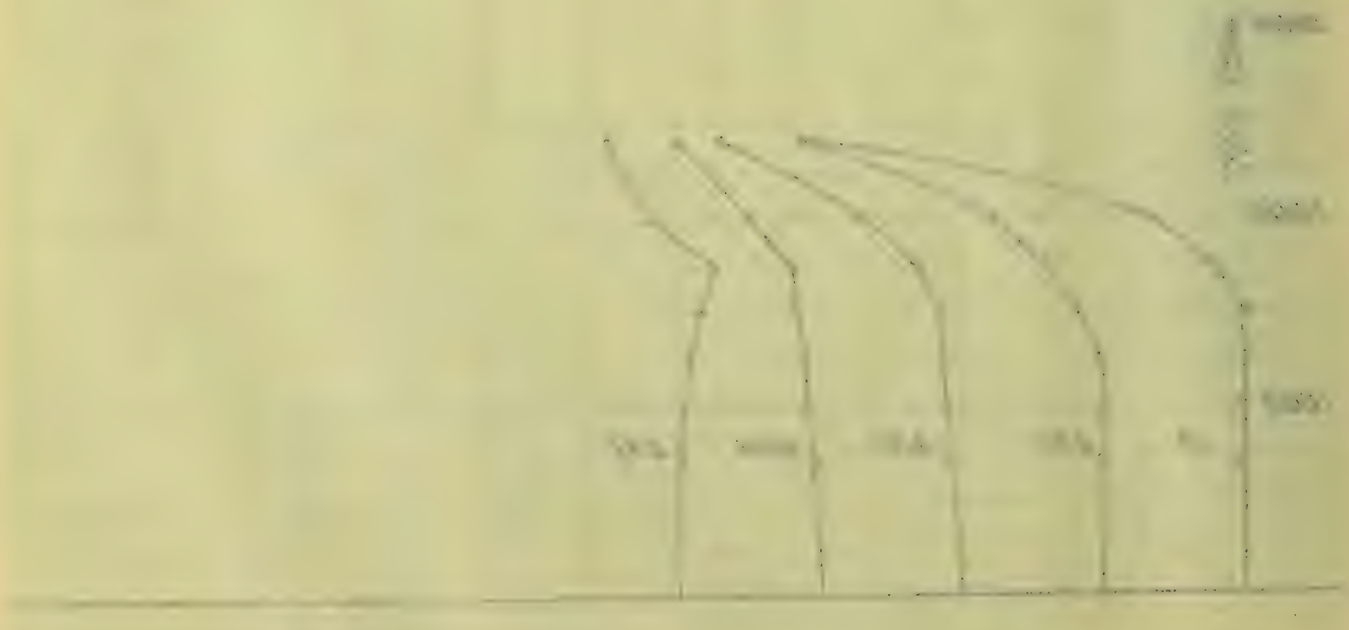


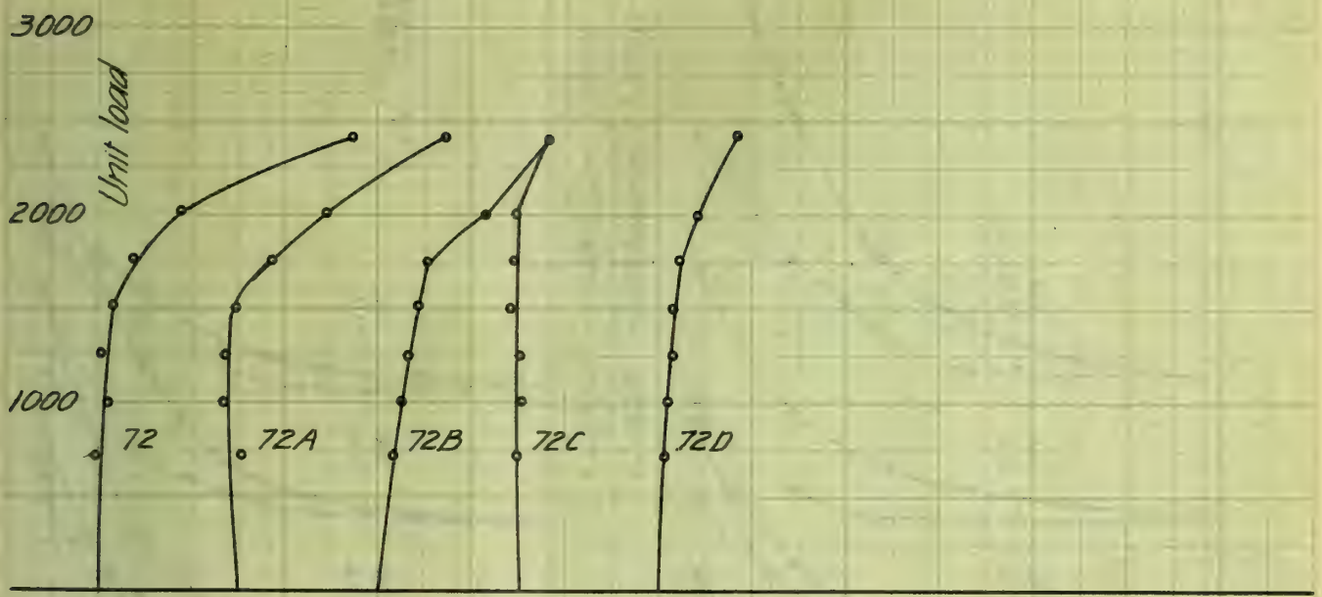
COL. 8917

←40000#/in.→
Tens. →



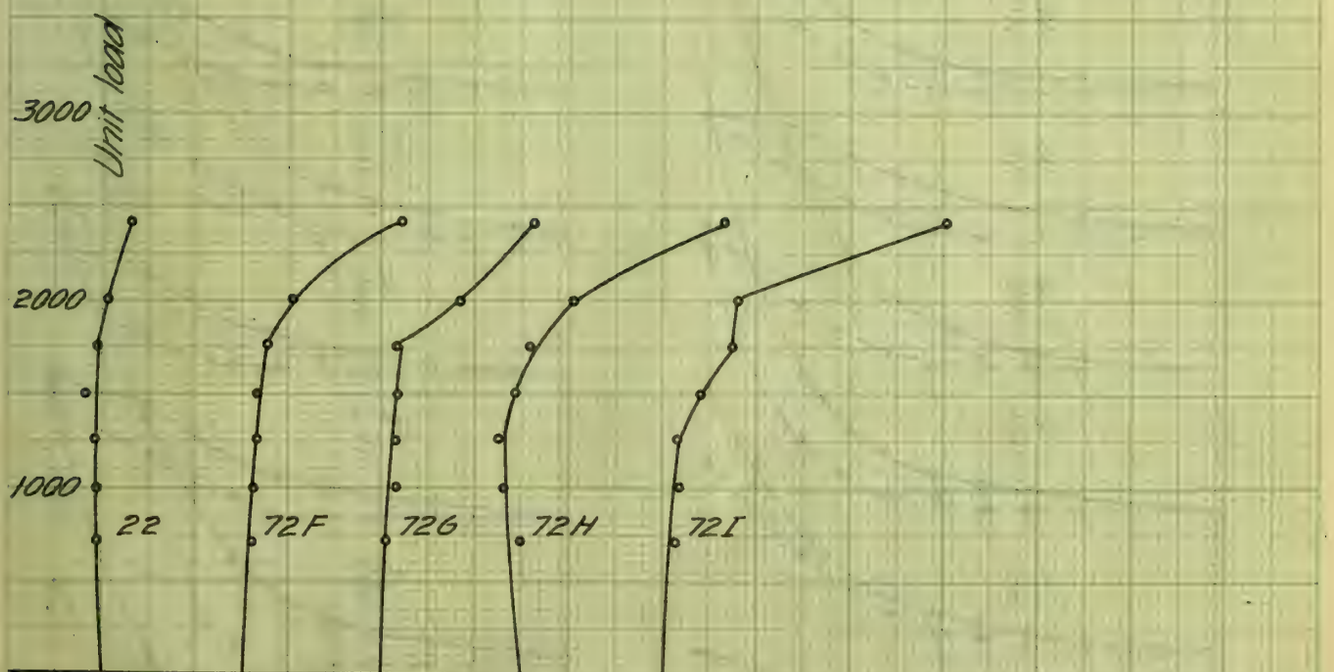






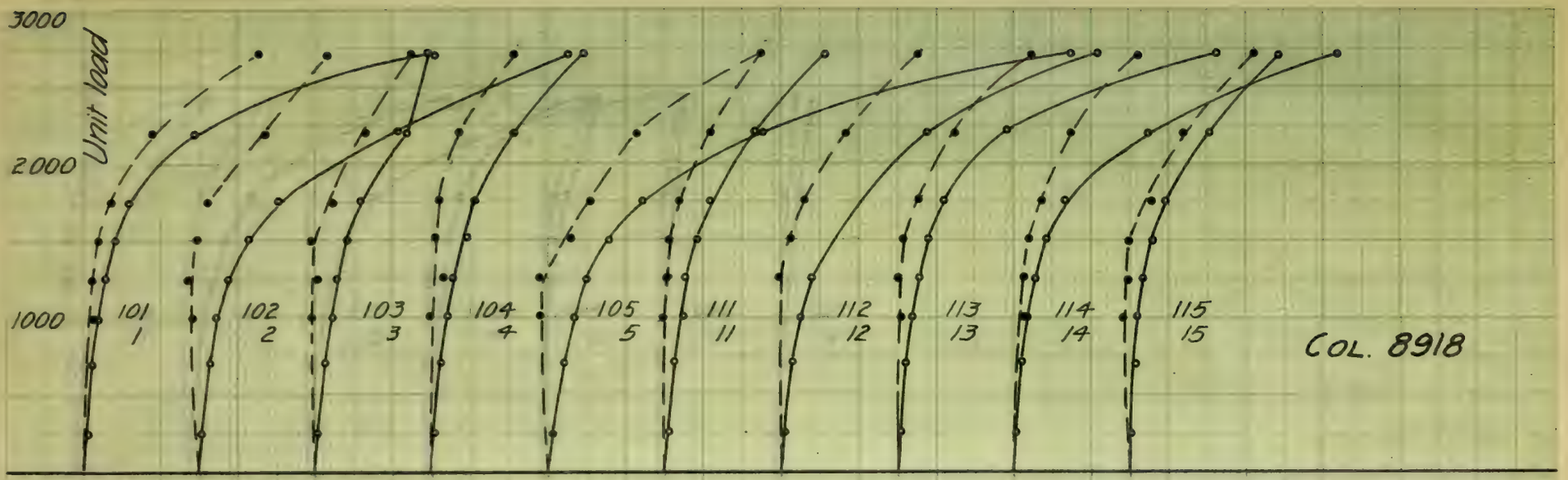
Col. 8917

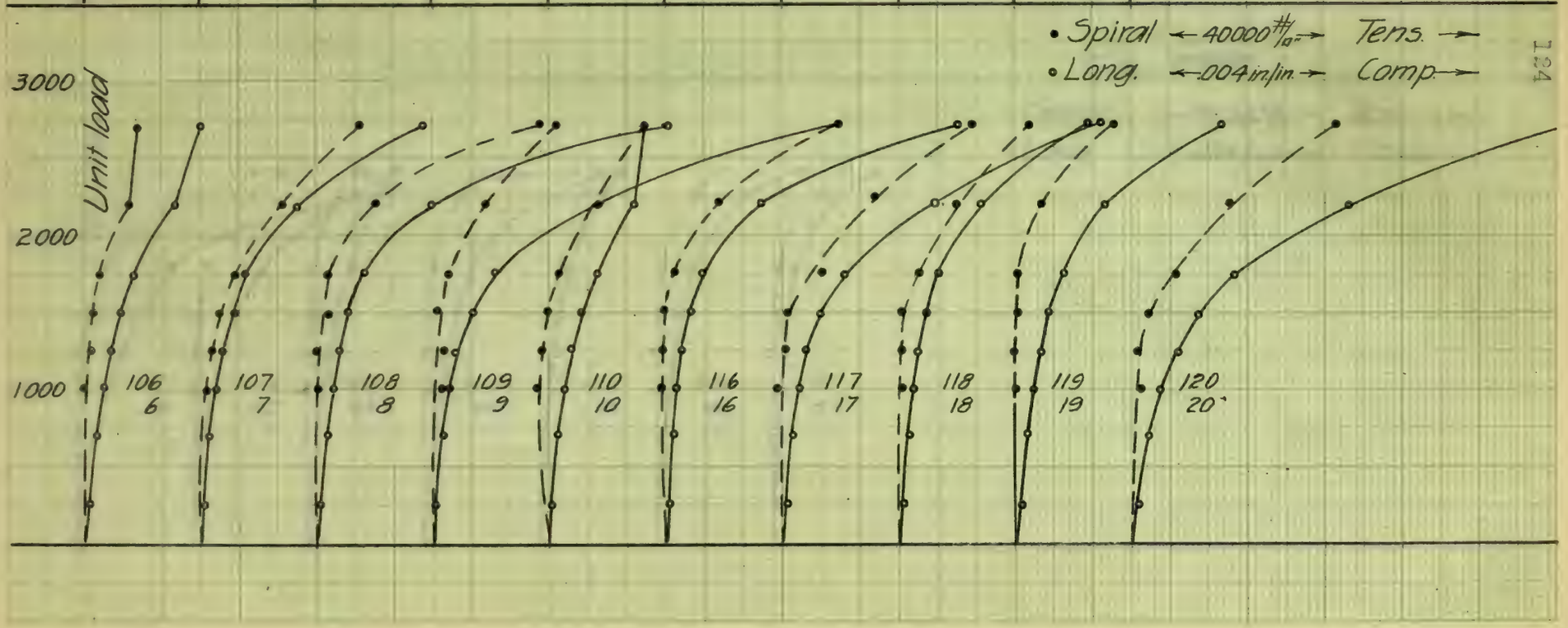
←40000#/□"→
Tens. →

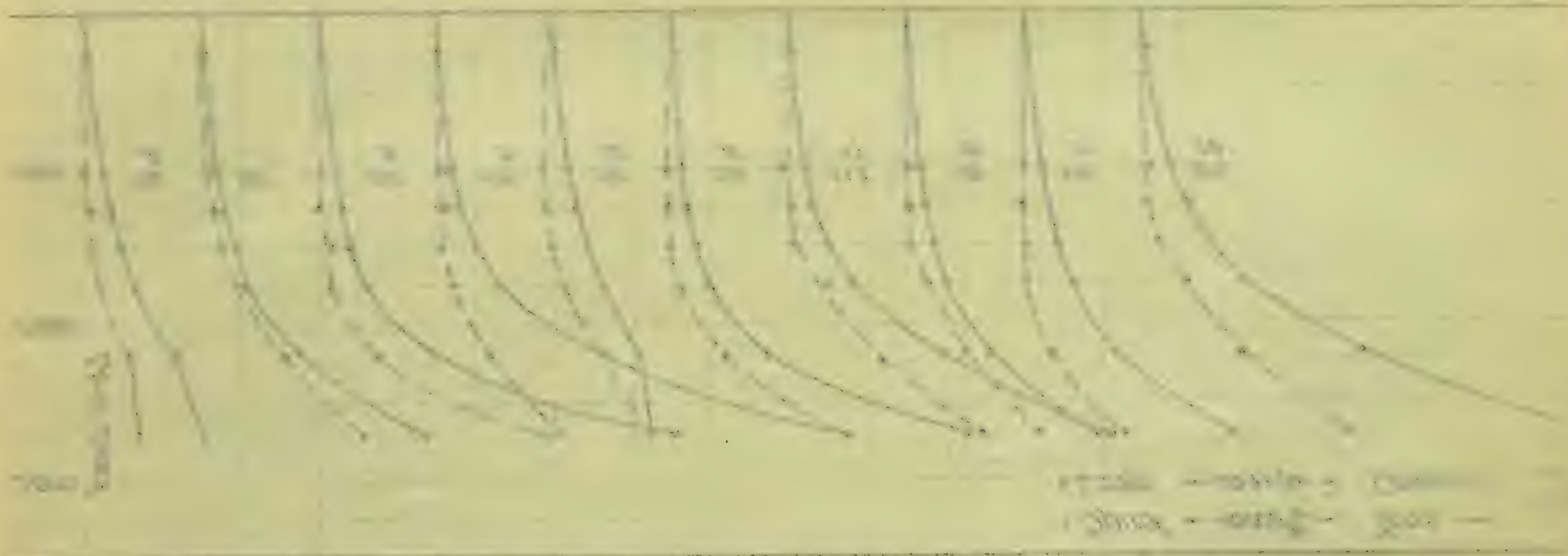


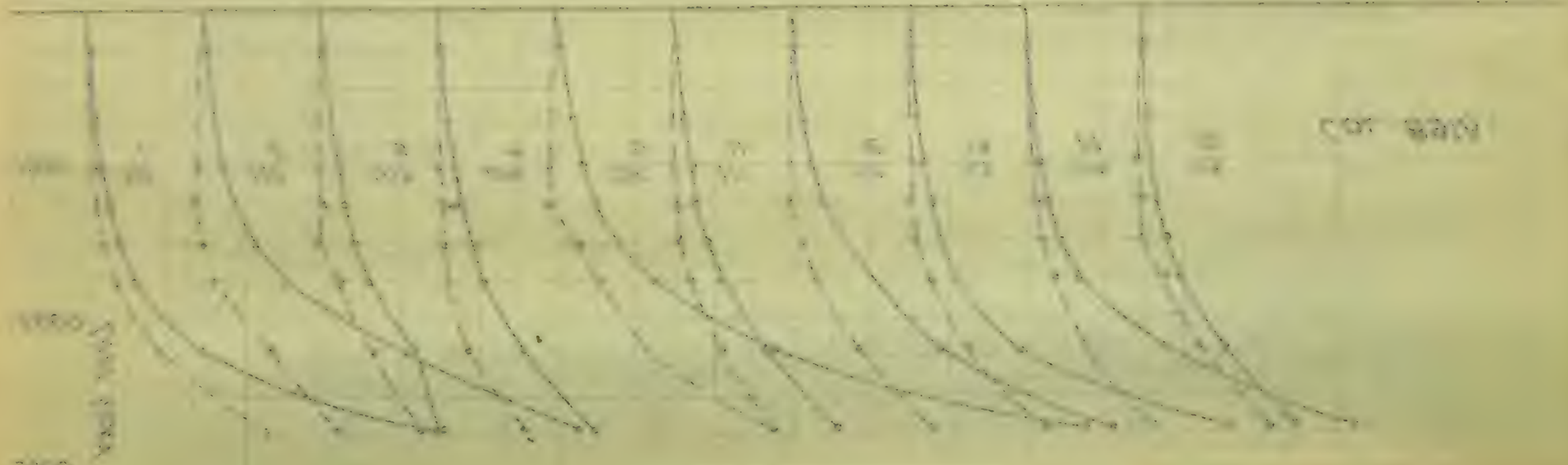


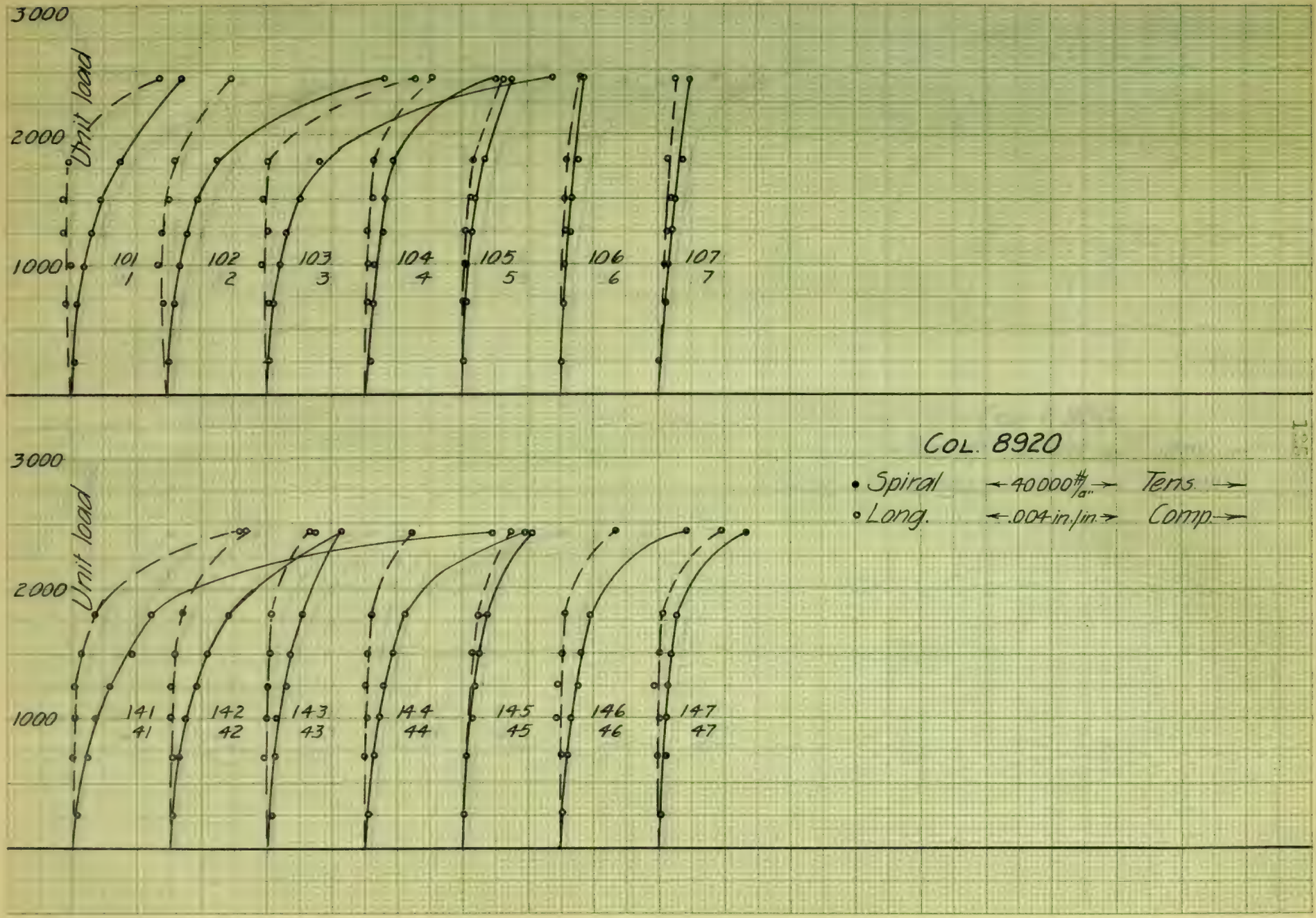



3000
2000
1000
Unit load
101
1
102
2
103
3
104
4
105
5
111
11
112
12
113
13
114
14
115
15
COL. 8918


• Spiral ← 40000 #/□" → Tens. →
• Long. ← .004 in/in → Comp. →
3000
2000
1000
Unit load
106
6
107
7
108
8
109
9
110
10
116
16
117
17
118
18
119
19
120
20

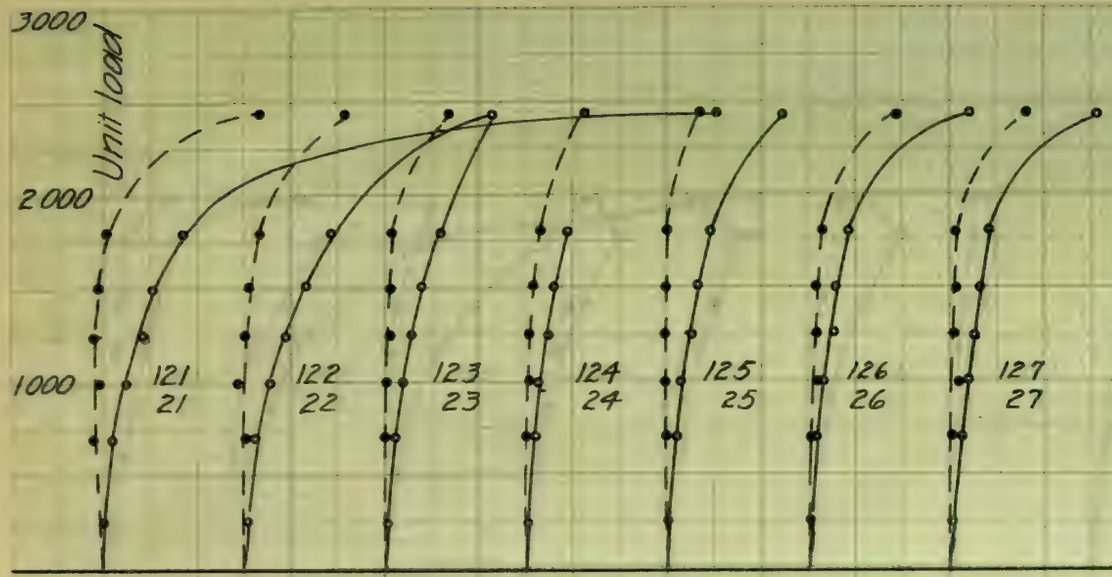


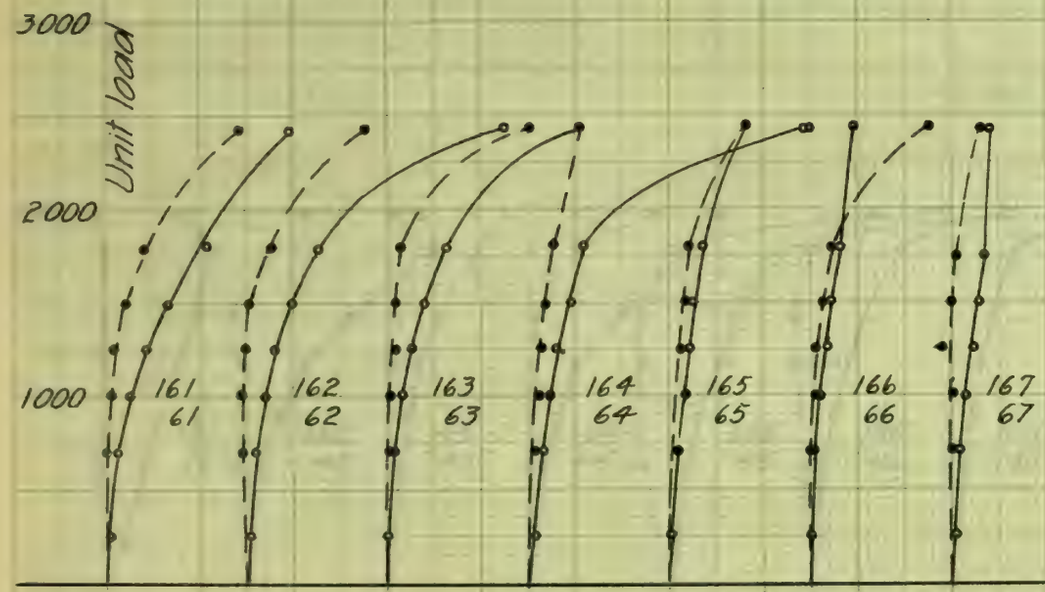



3000
2000
1000
Unit load
101
1
102
2
103
3
104
4
105
5
106
6
107
7
3000
2000
1000
Unit load
141
41
142
42
143
43
144
44
145
45
146
46
147
47
COL. 8920
• Spiral ← 40000 #/□" → Tens. →
○ Long. ← .004 in./in. → Comp. →







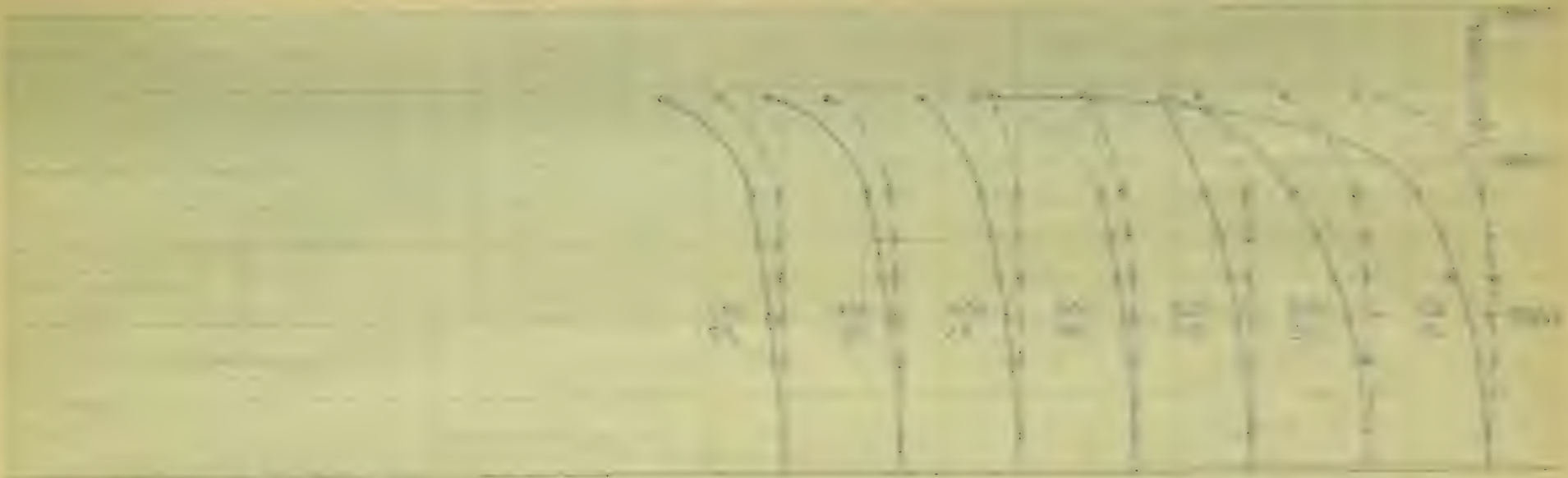


COL. 8920

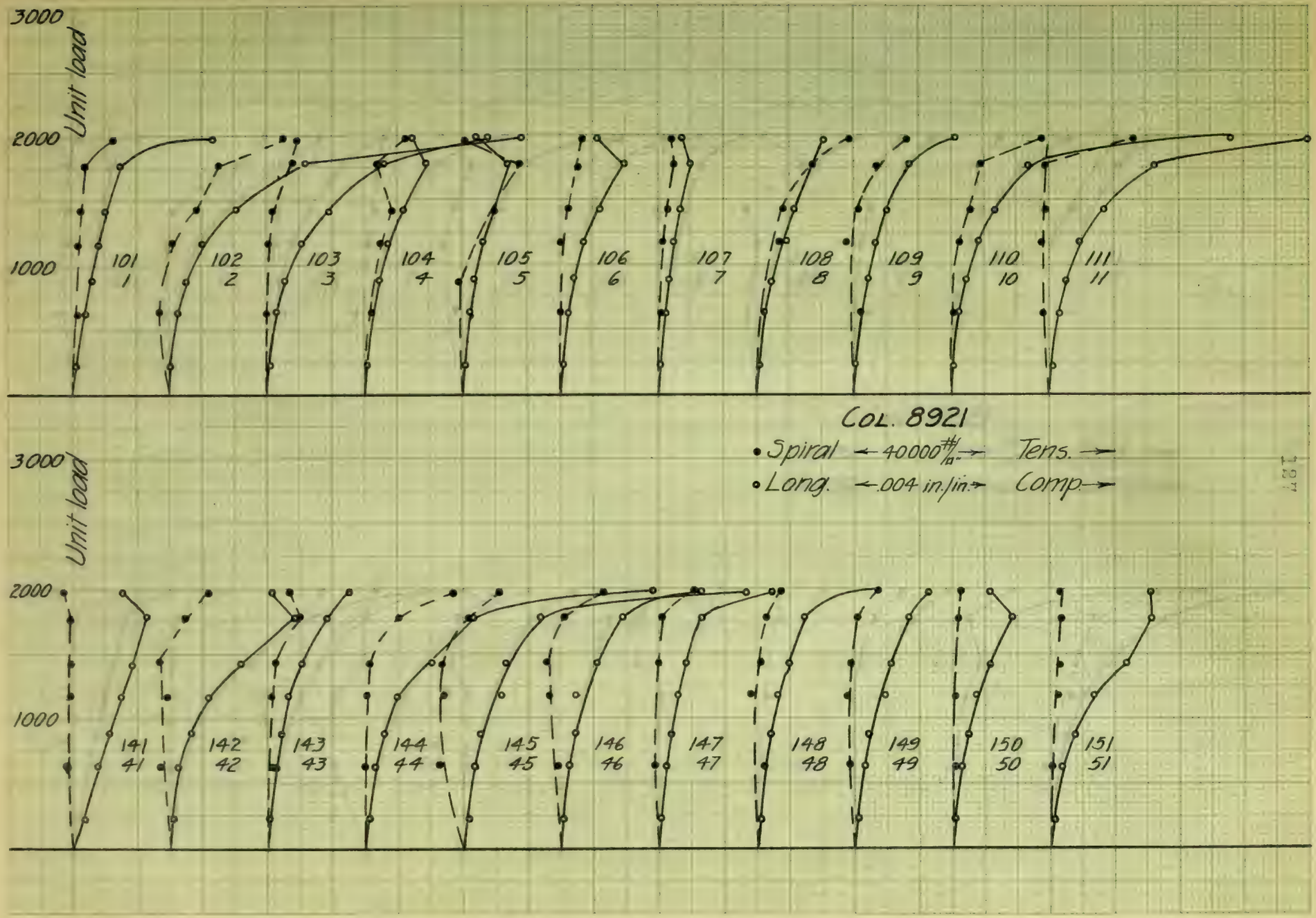
• Spiral ← 40000#/in. → Tens. →

• Long. ← .004 in./in. → Comp. →

135



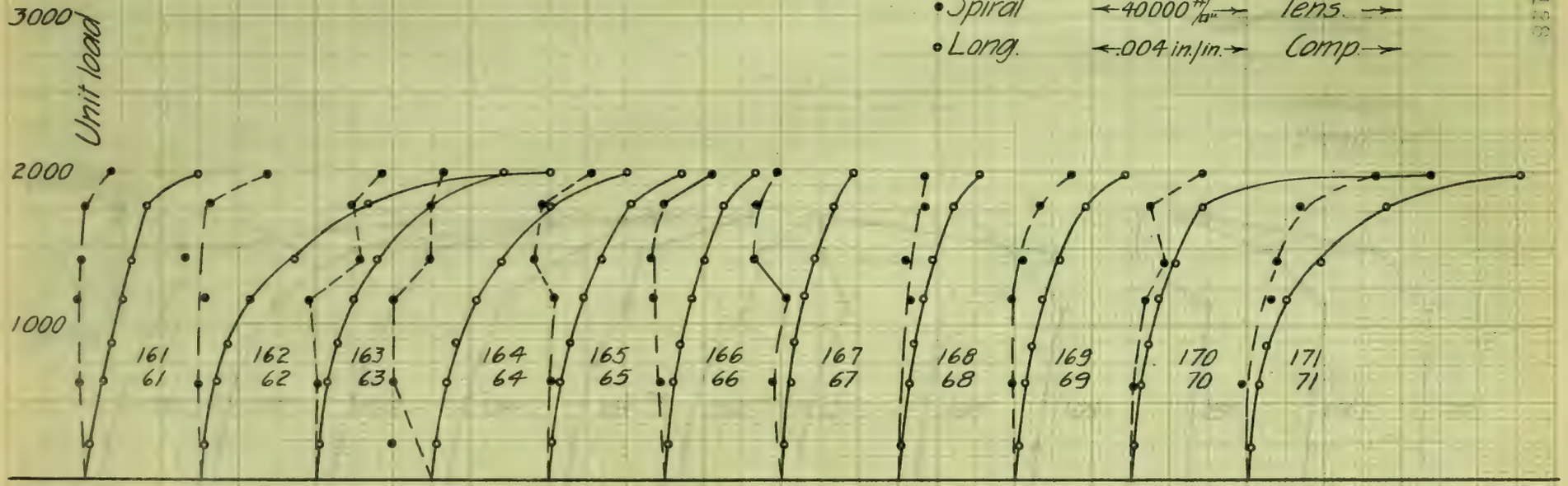


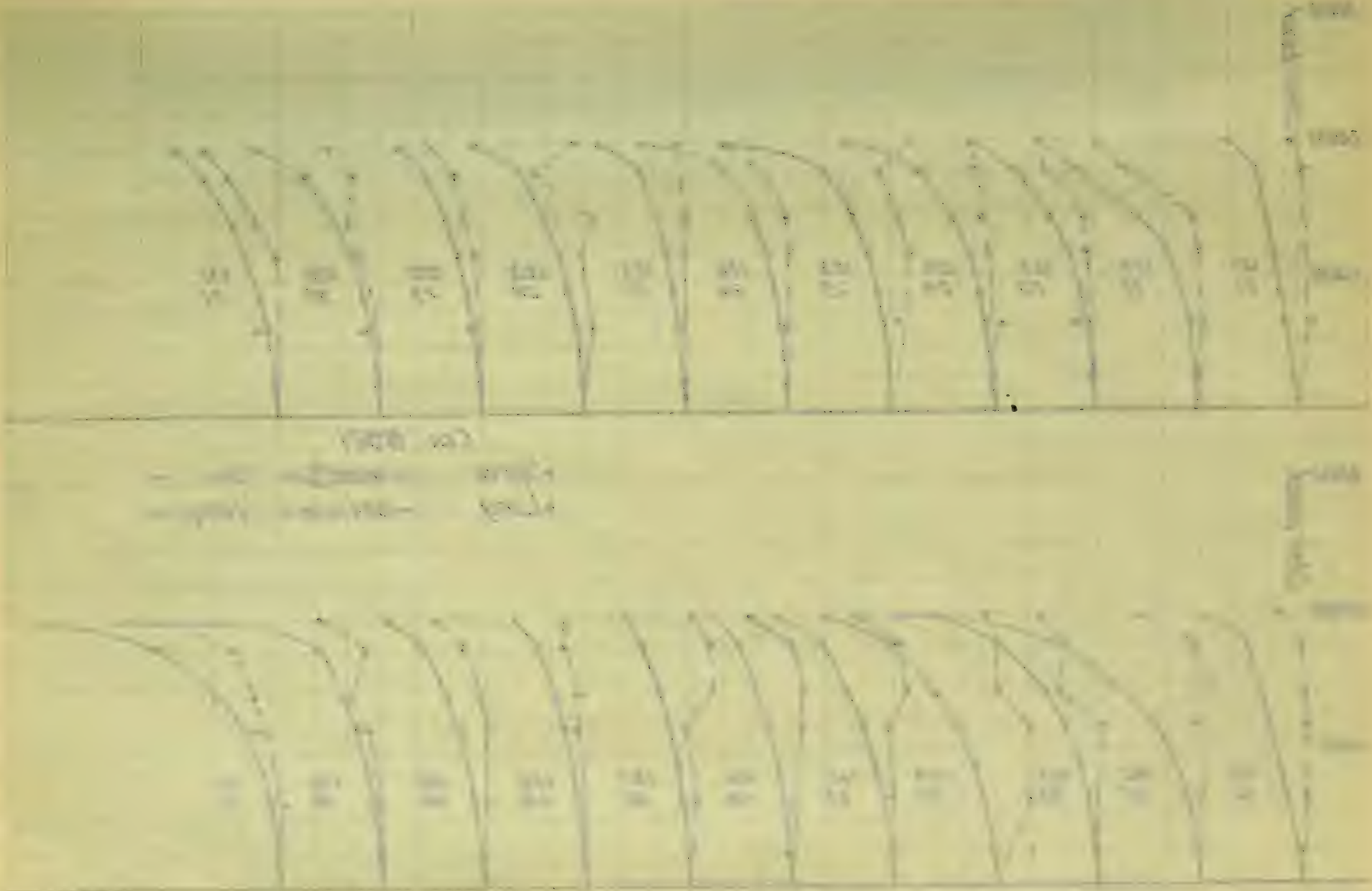

3000
Unit load
2000
1000
101
1
102
2
103
3
104
4
105
5
106
6
107
7
108
8
109
9
110
10
111
11
COL. 8921
• Spiral ← 40000 #/in² → Tens. →
• Long. ← .004 in./in. → Comp. →
3000
Unit load
2000
1000
141
41
142
42
143
43
144
44
145
45
146
46
147
47
148
48
149
49
150
50
151
51

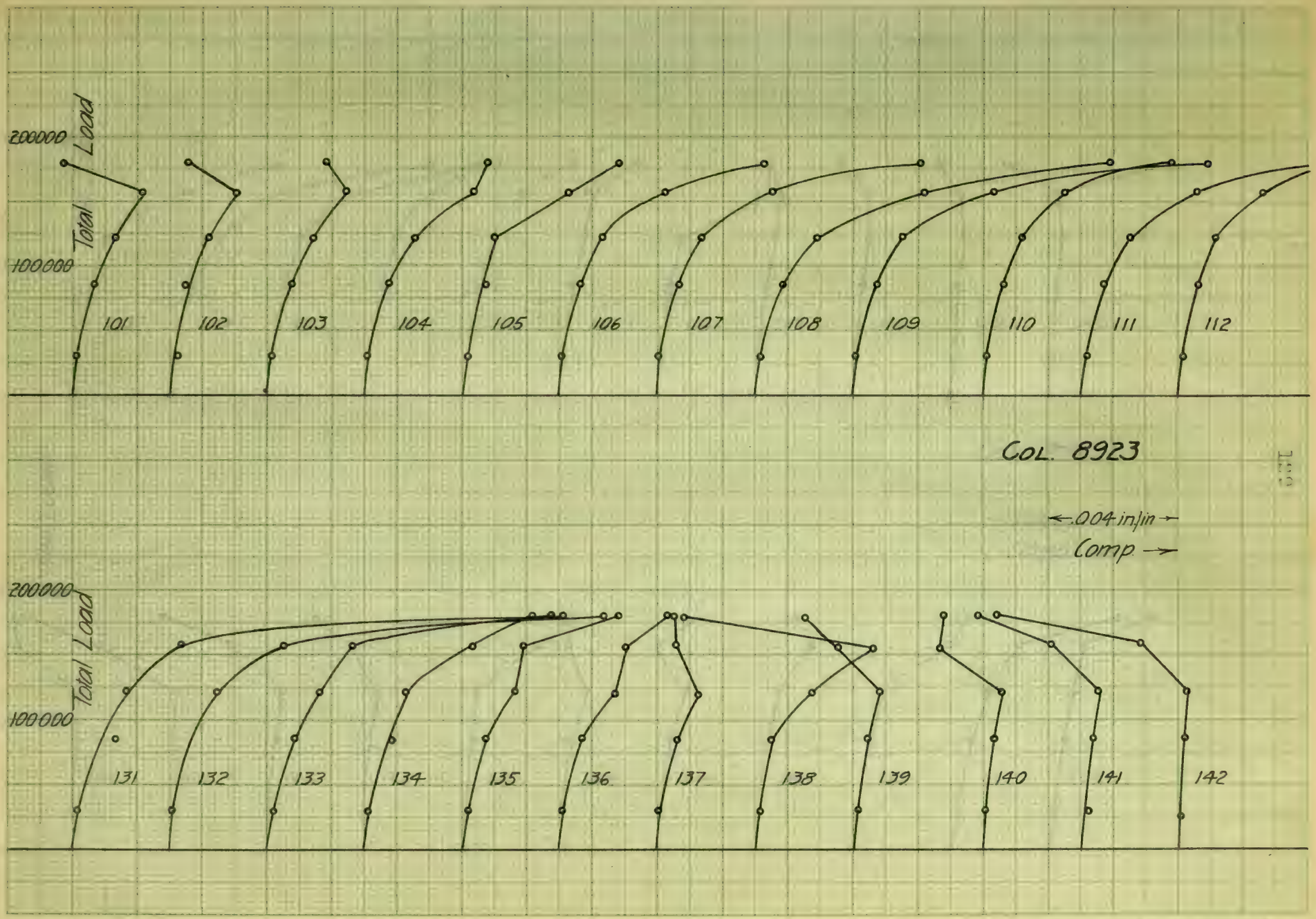


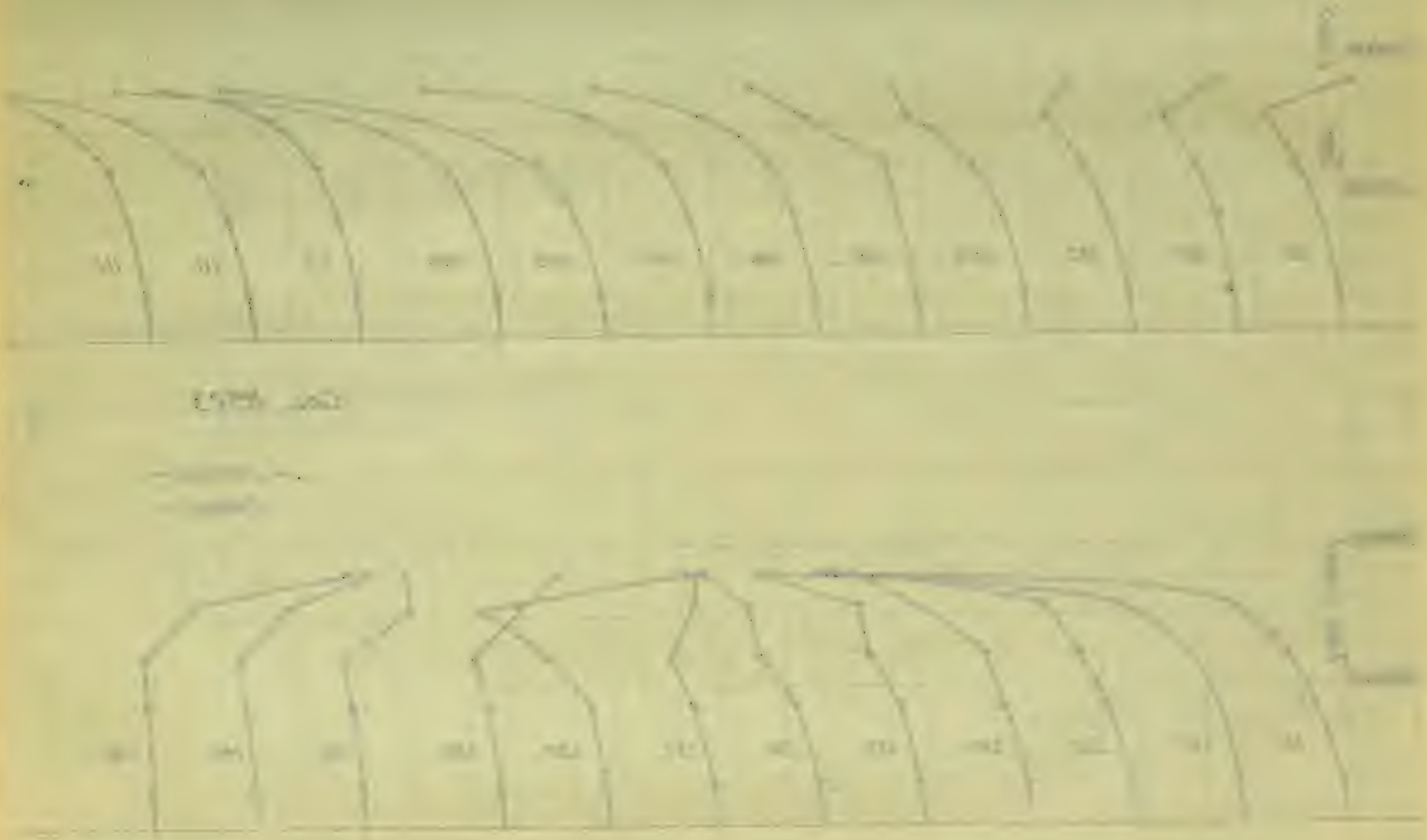
COL. 8921

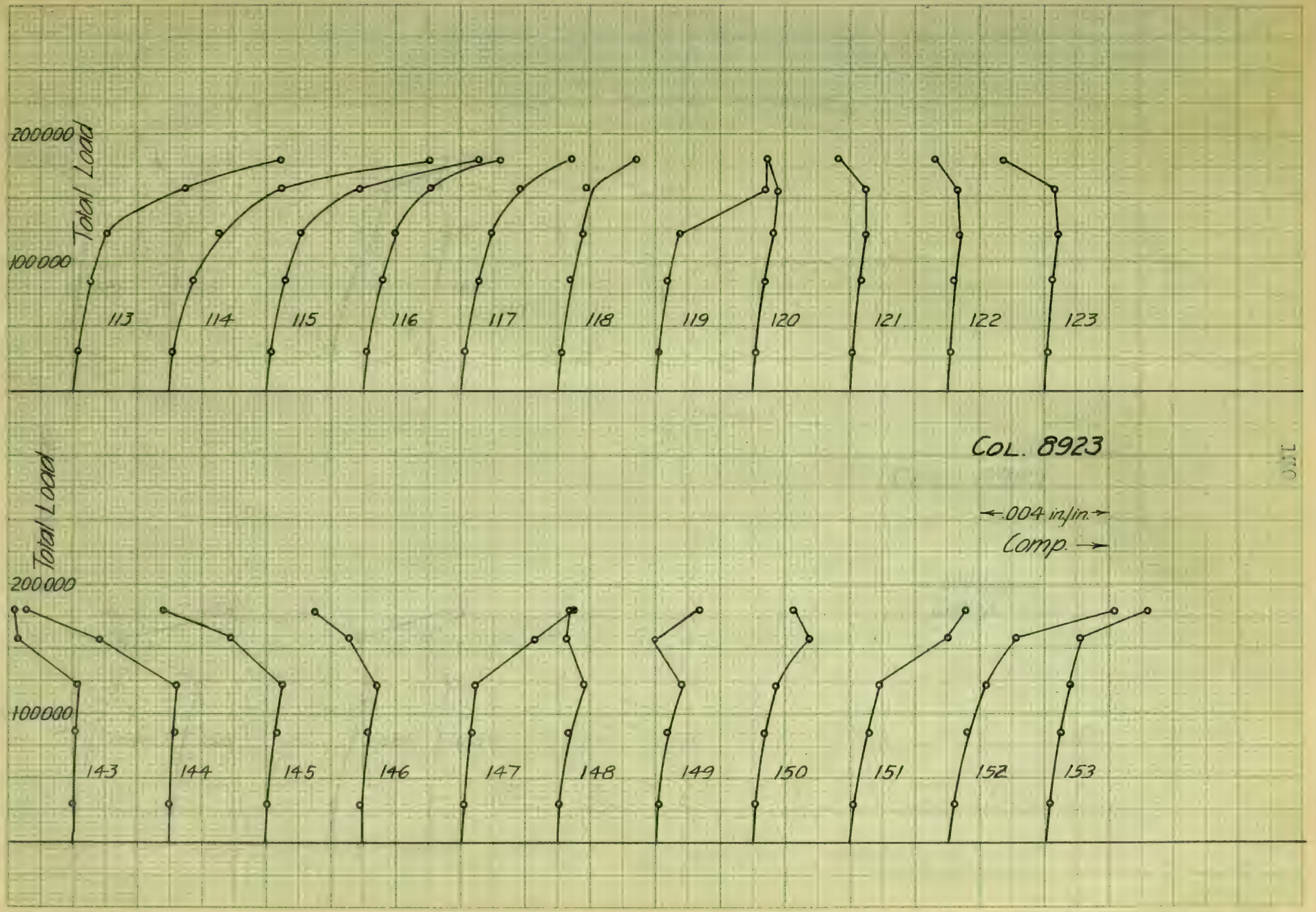
• Spiral ←40000 #/in²→ Tens. →
• Long. ←.004 in./in.→ Comp. →

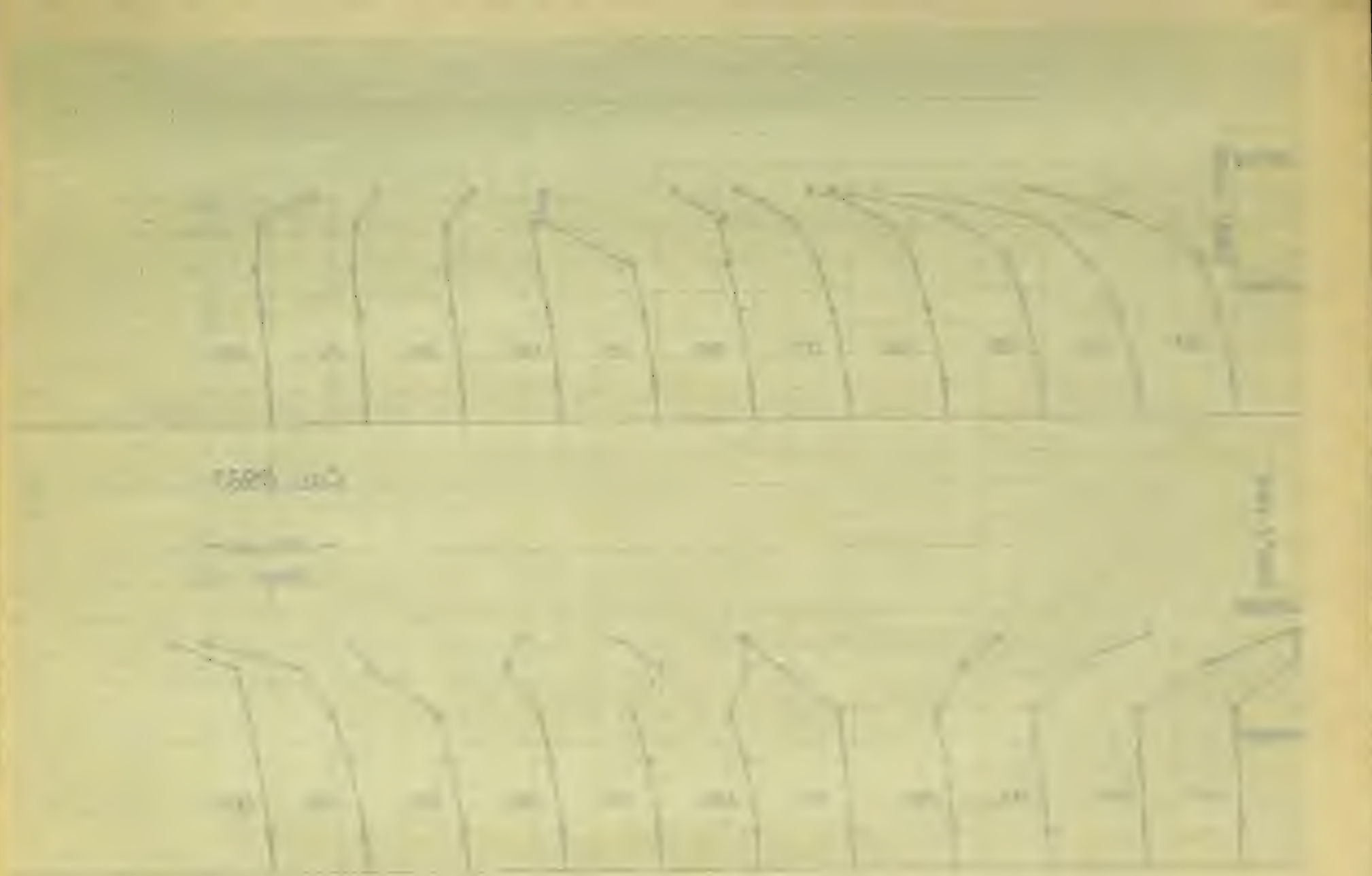


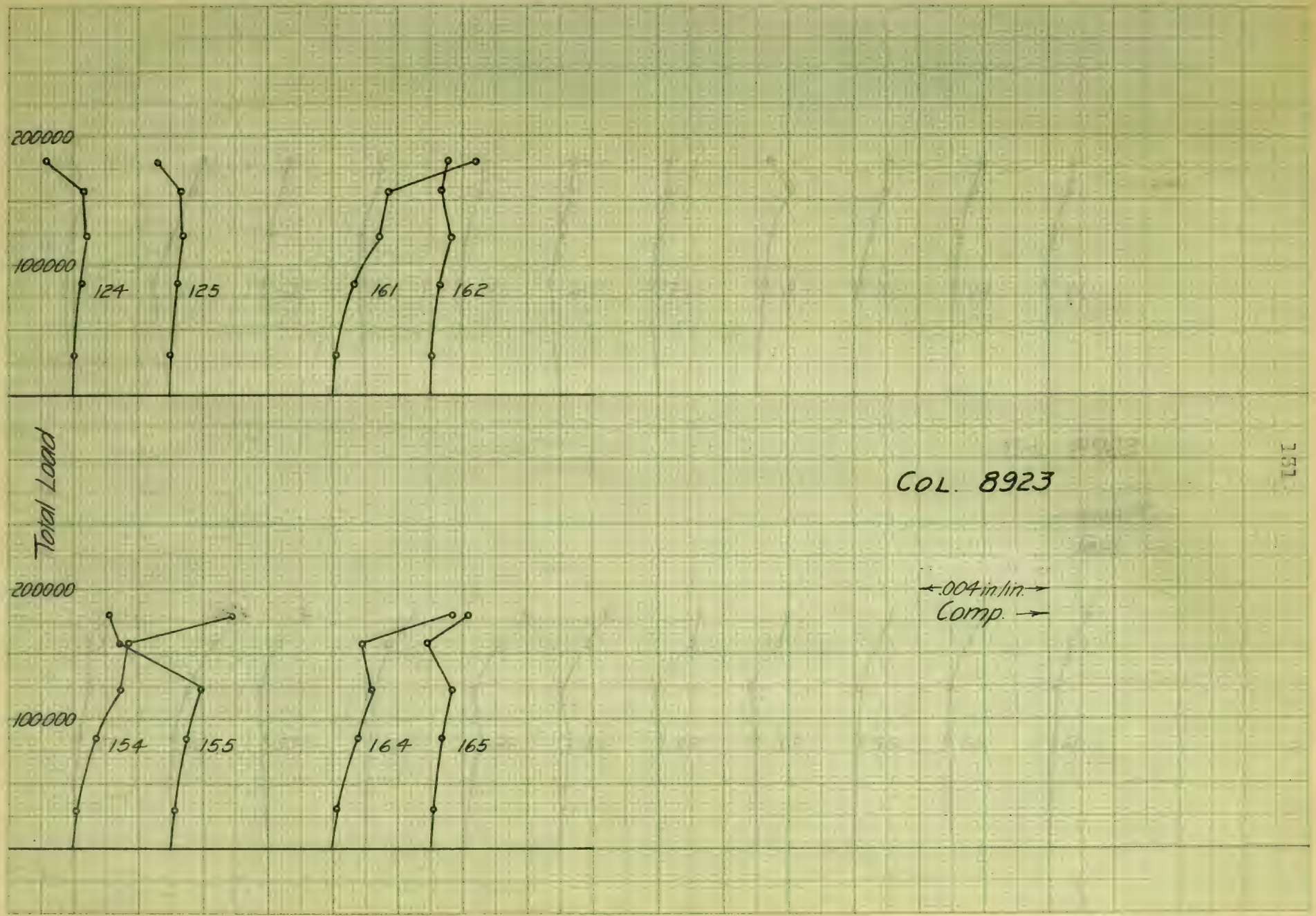



200000
Load
Total
100000
101
102
103
104
105
106
107
108
109
110
111
112
COL. 8923
.004 in/in
Comp.
200000
Total Load
100000
131
132
133
134
135
136
137
138
139
140
141
142

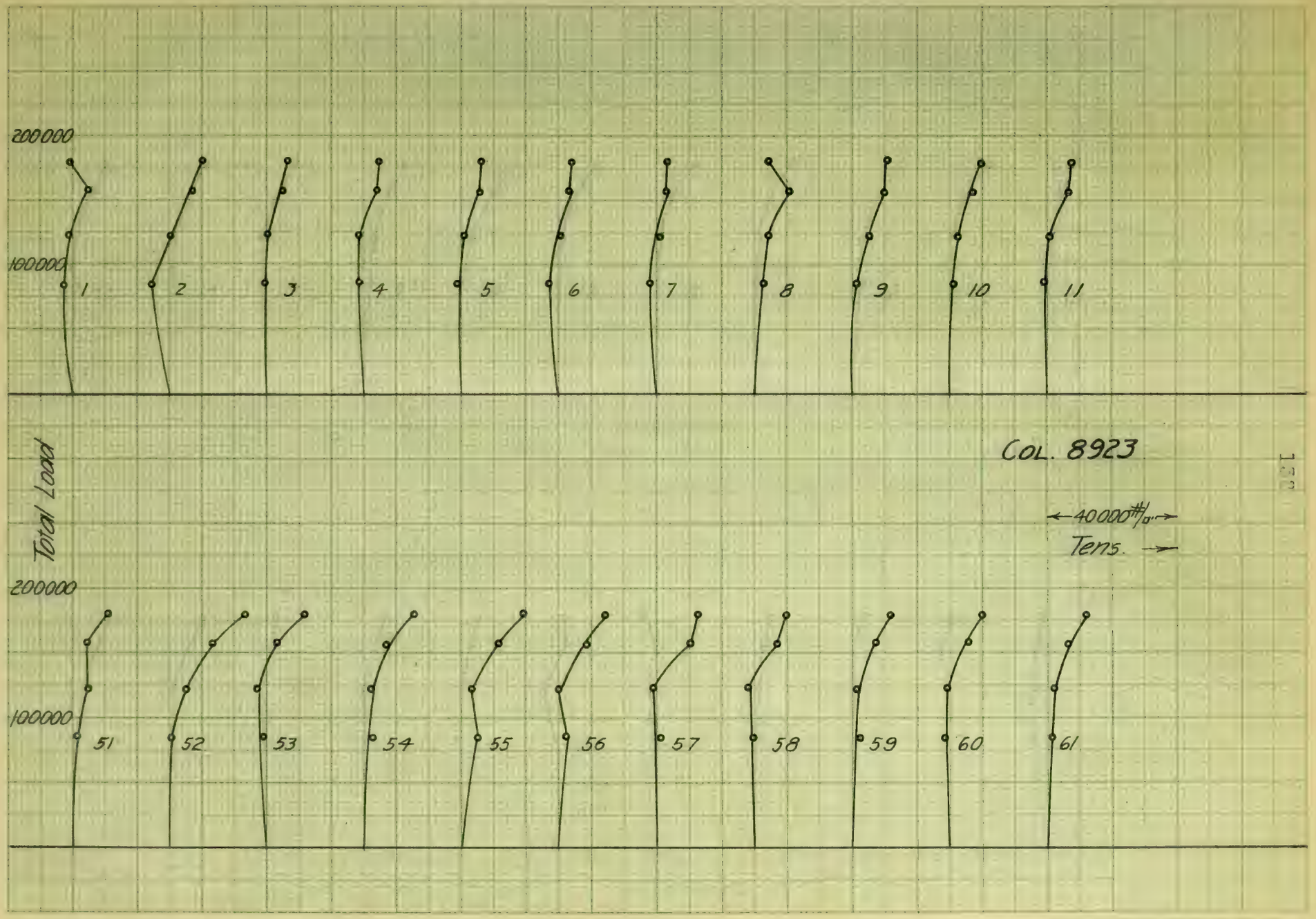


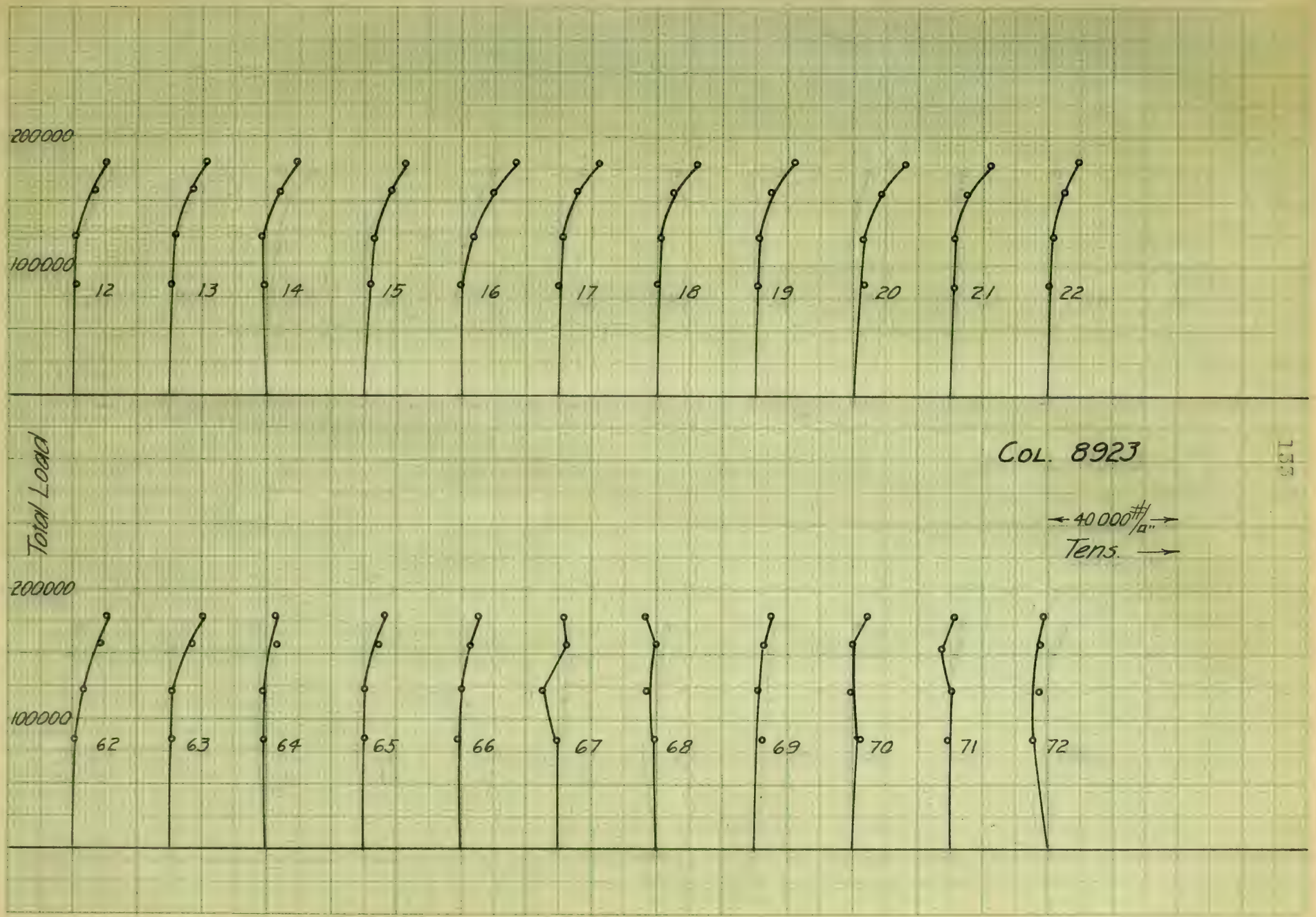

200000
Total Load
100000
113
114
115
116
117
118
119
120
121
122
123
COL. 8923
.004 in./in.
Comp.
Total Load
200000
100000
143
144
145
146
147
148
149
150
151
152
153

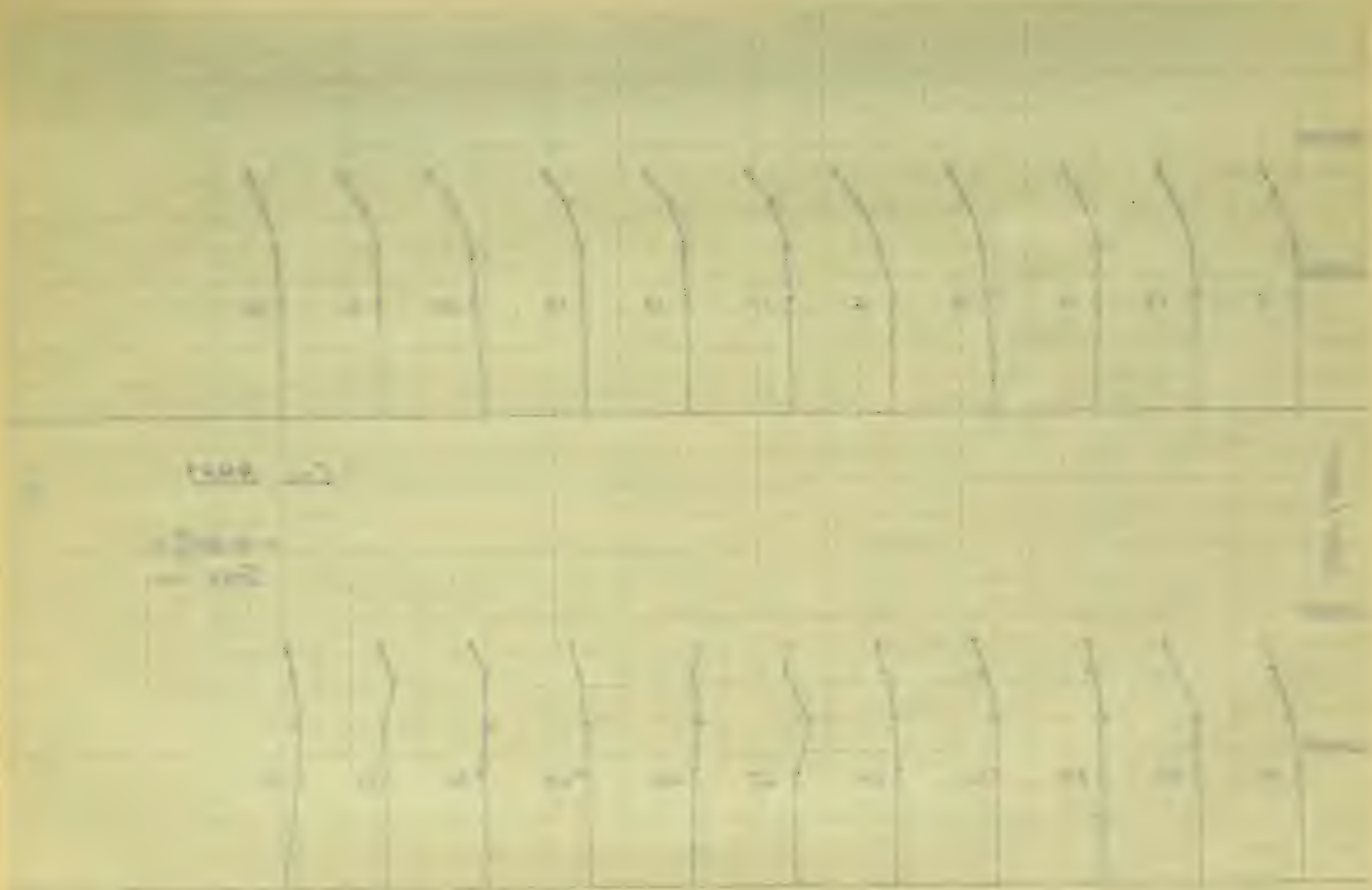


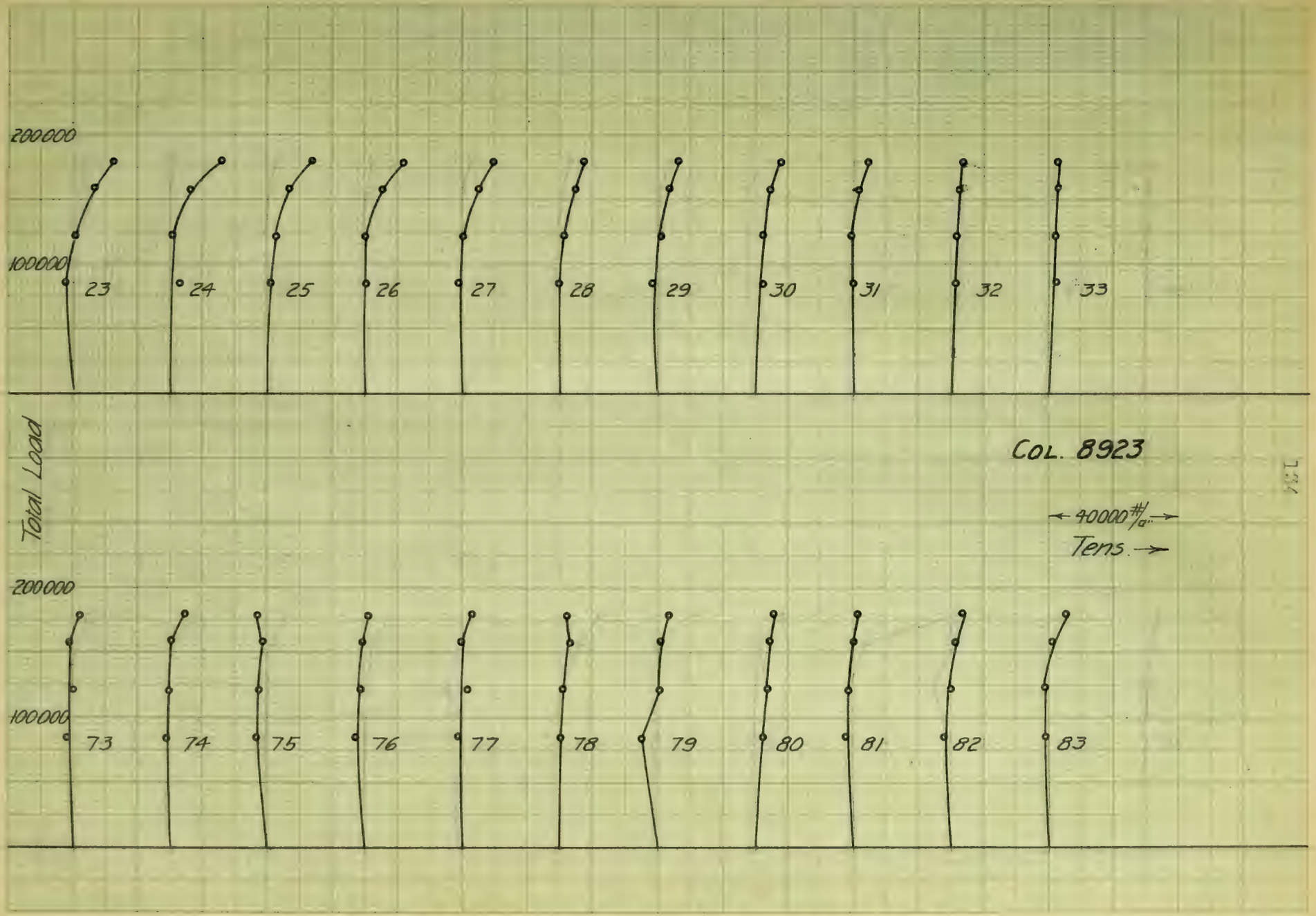

200000
100000
124
125
161
162
Total Load
200000
100000
154
155
164
165
COL. 8923
.004 in/in
Comp.

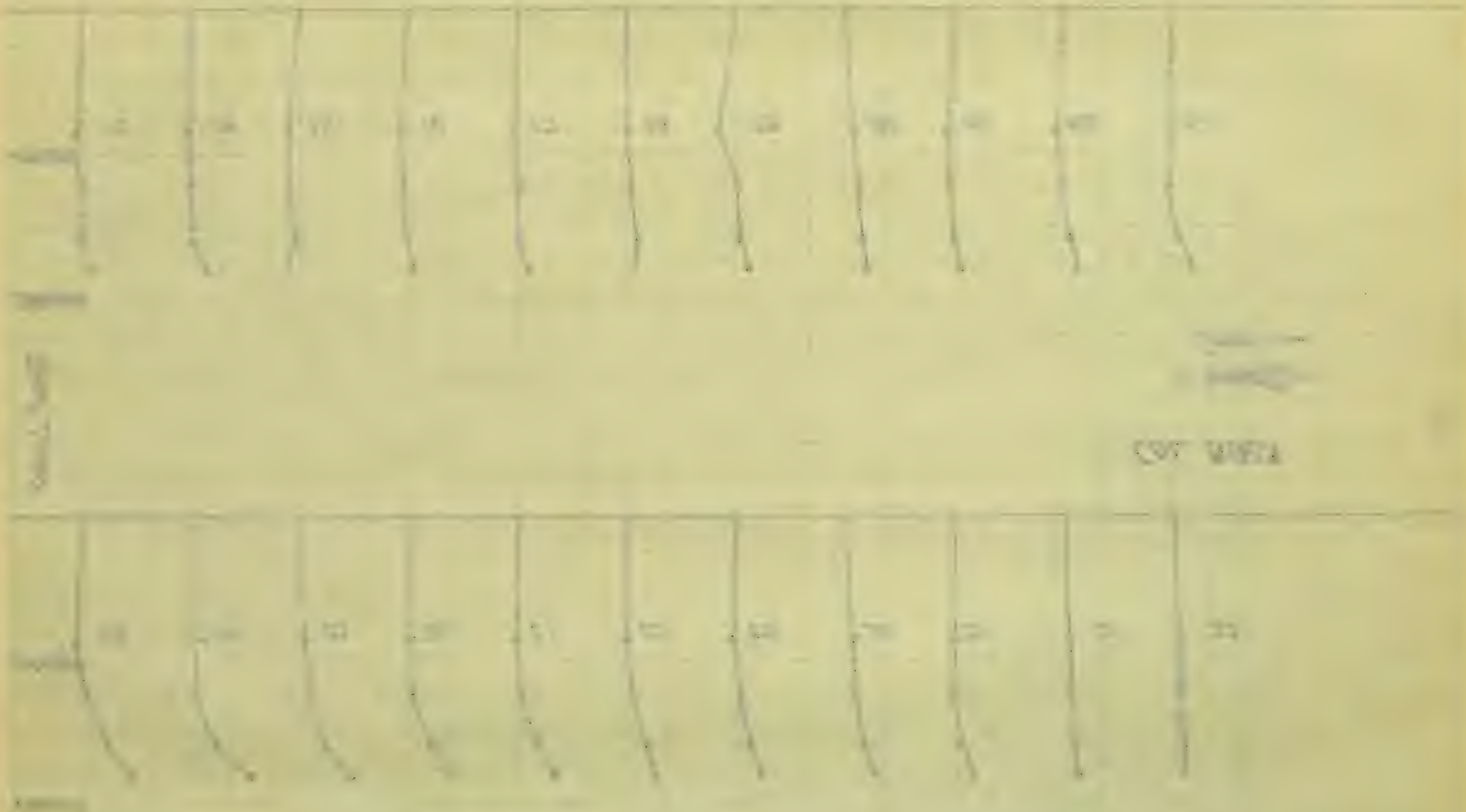


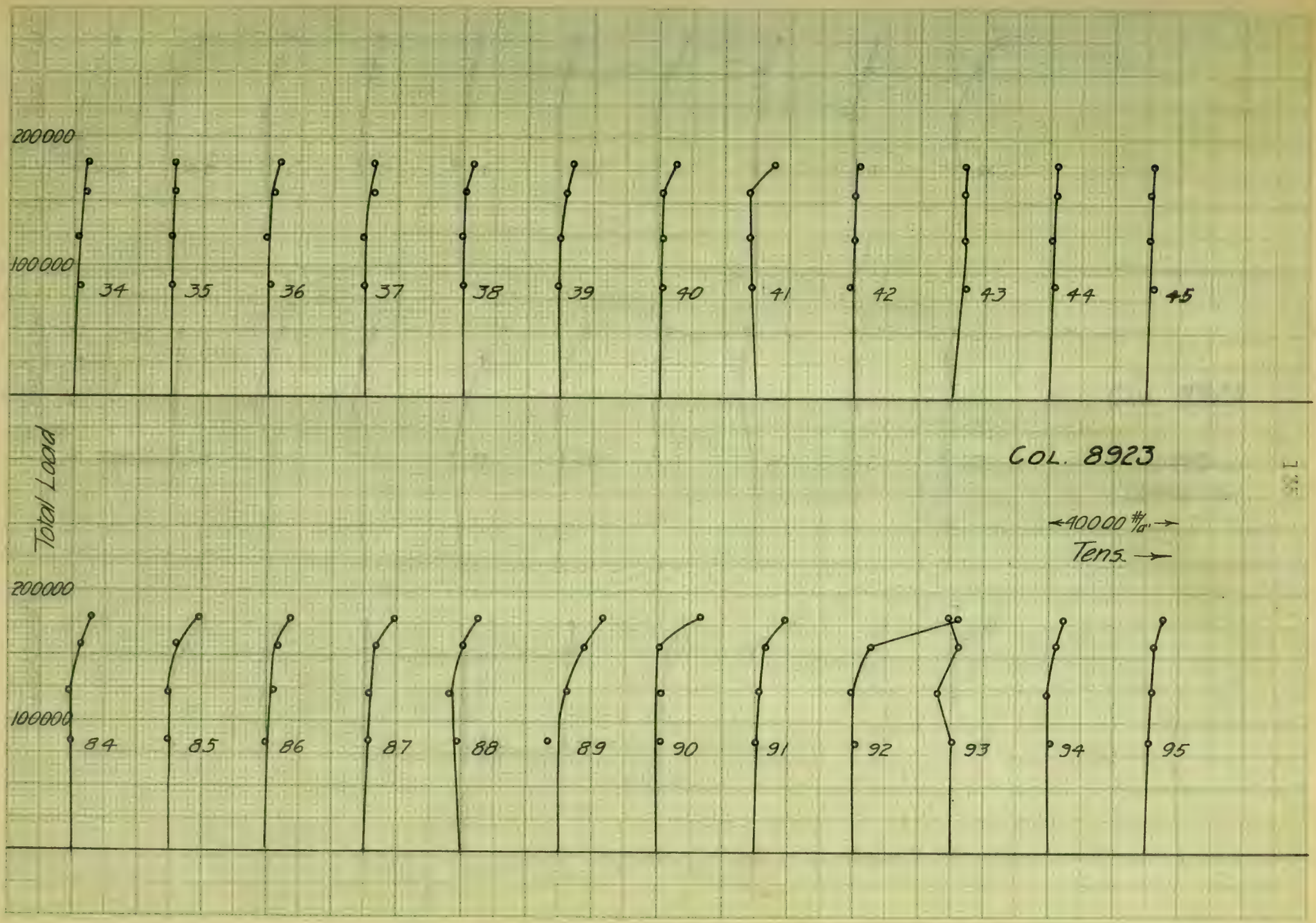

200000
100000
1
2
3
4
5
6
7
8
9
10
11
Total Load
COL. 8923
40000#/in.
Tens.
200000
100000
51
52
53
54
55
56
57
58
59
60
61

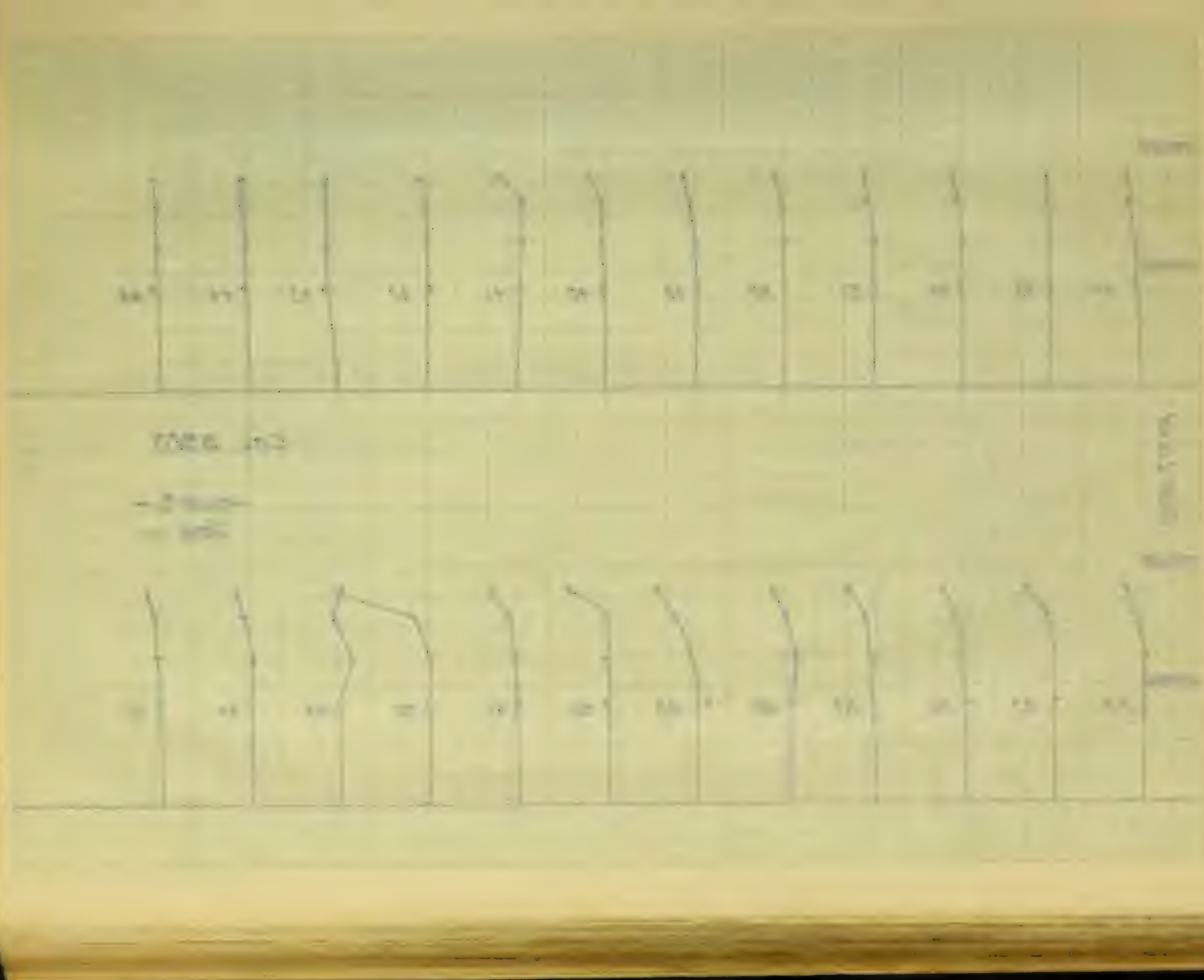

200000
100000
12
13
14
15
16
17
18
19
20
21
22
Total Load
Col. 8923
40000 #/a"
Tens.
200000
100000
62
63
64
65
66
67
68
69
70
71
72

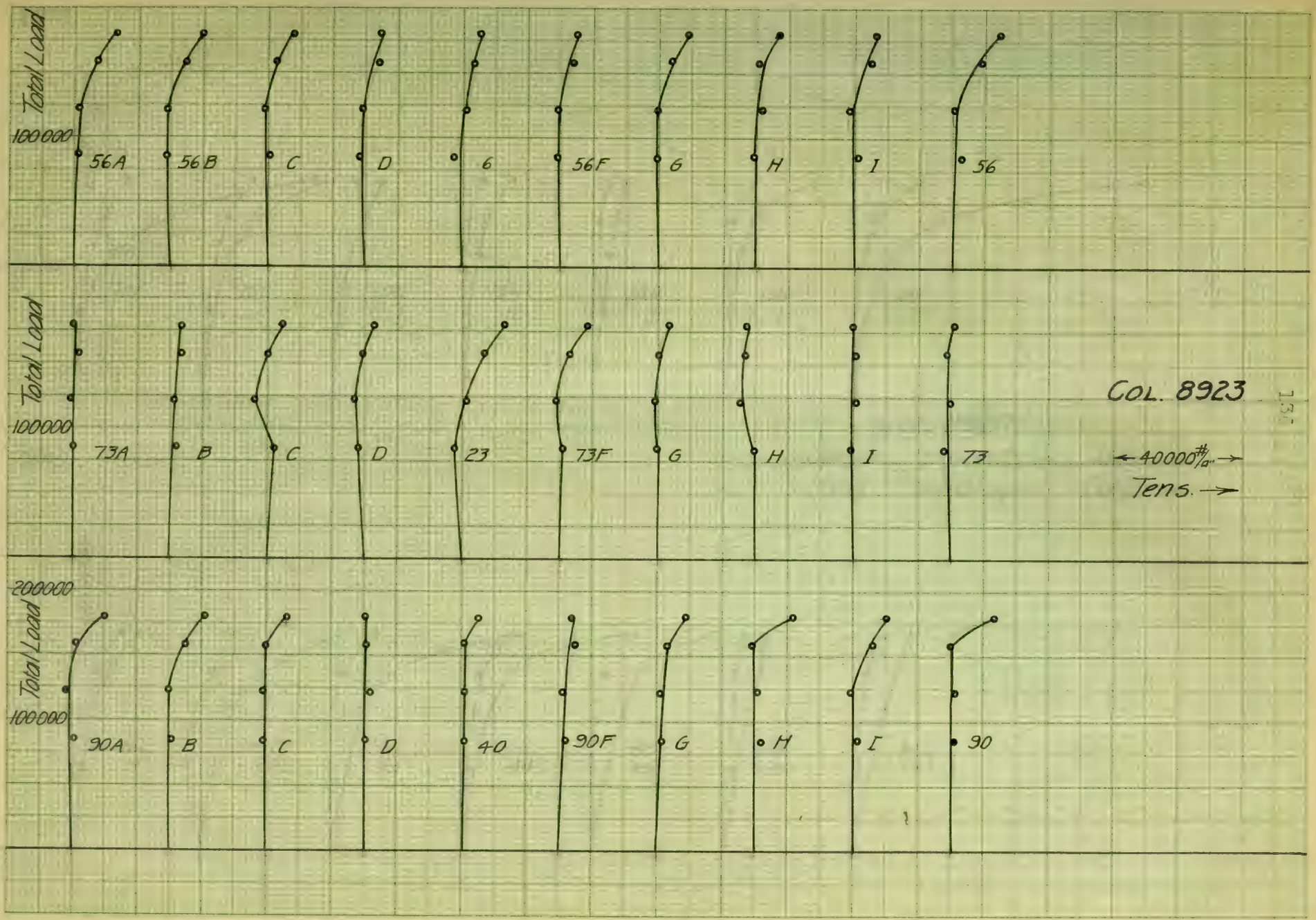


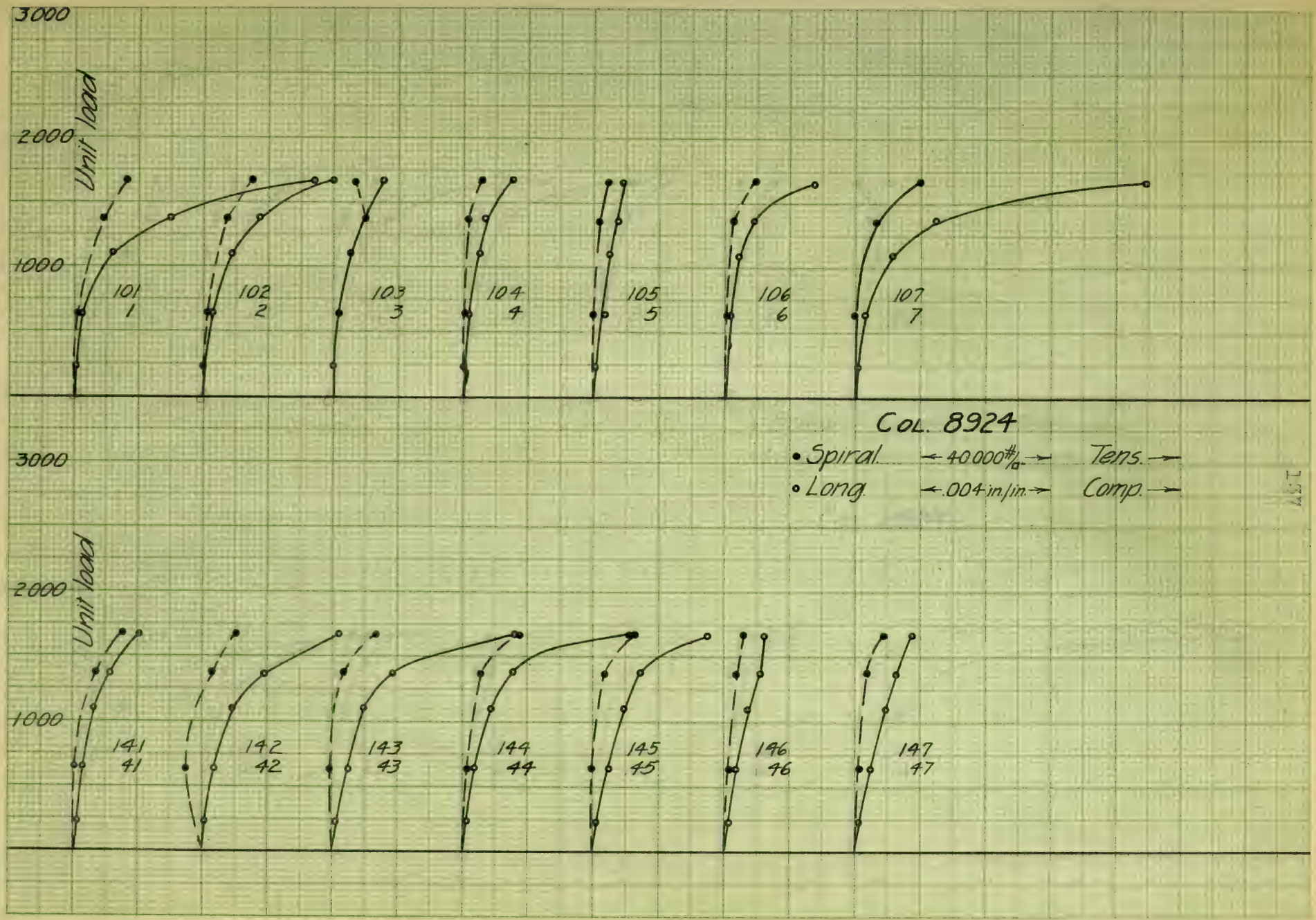

200000
100000
23
24
25
26
27
28
29
30
31
32
33
Total Load
COL. 8923
40000 #/a"
Tens.
200000
100000
73
74
75
76
77
78
79
80
81
82
83

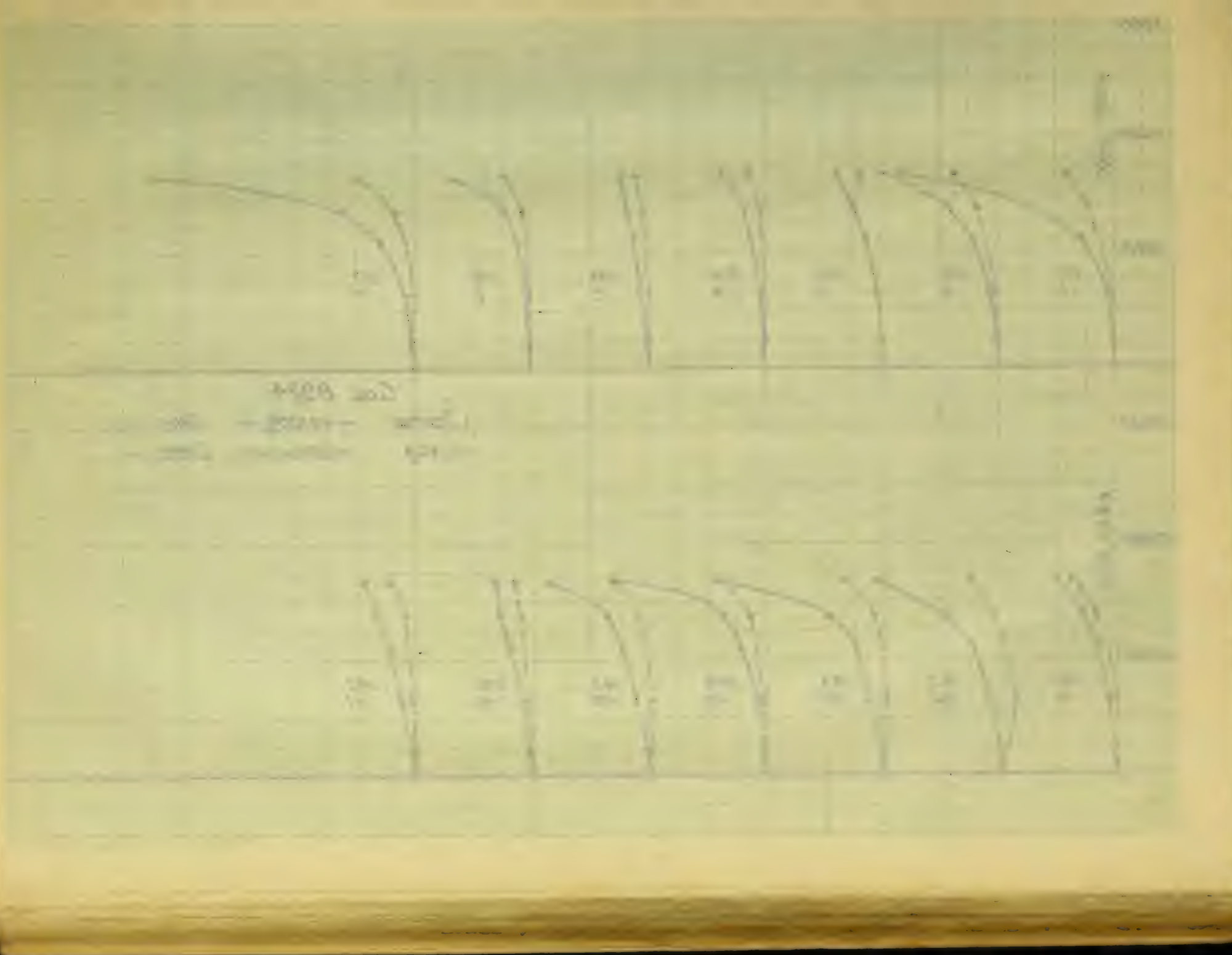


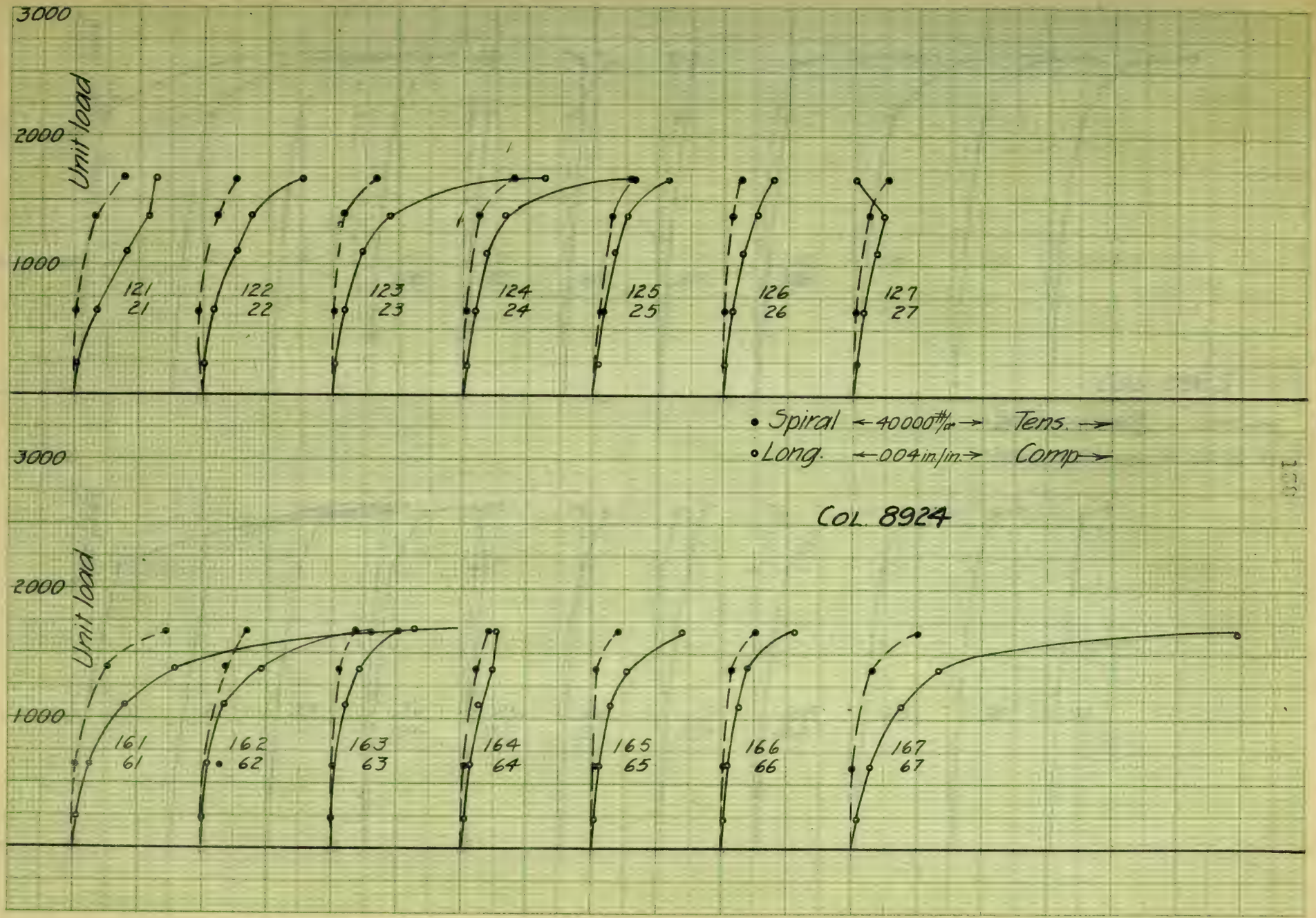

200000
100000
34
35
36
37
38
39
40
41
42
43
44
45
Total Load
COL. 8923
←40000 #/in.→
Tens →
200000
100000
84
85
86
87
88
89
90
91
92
93
94
95

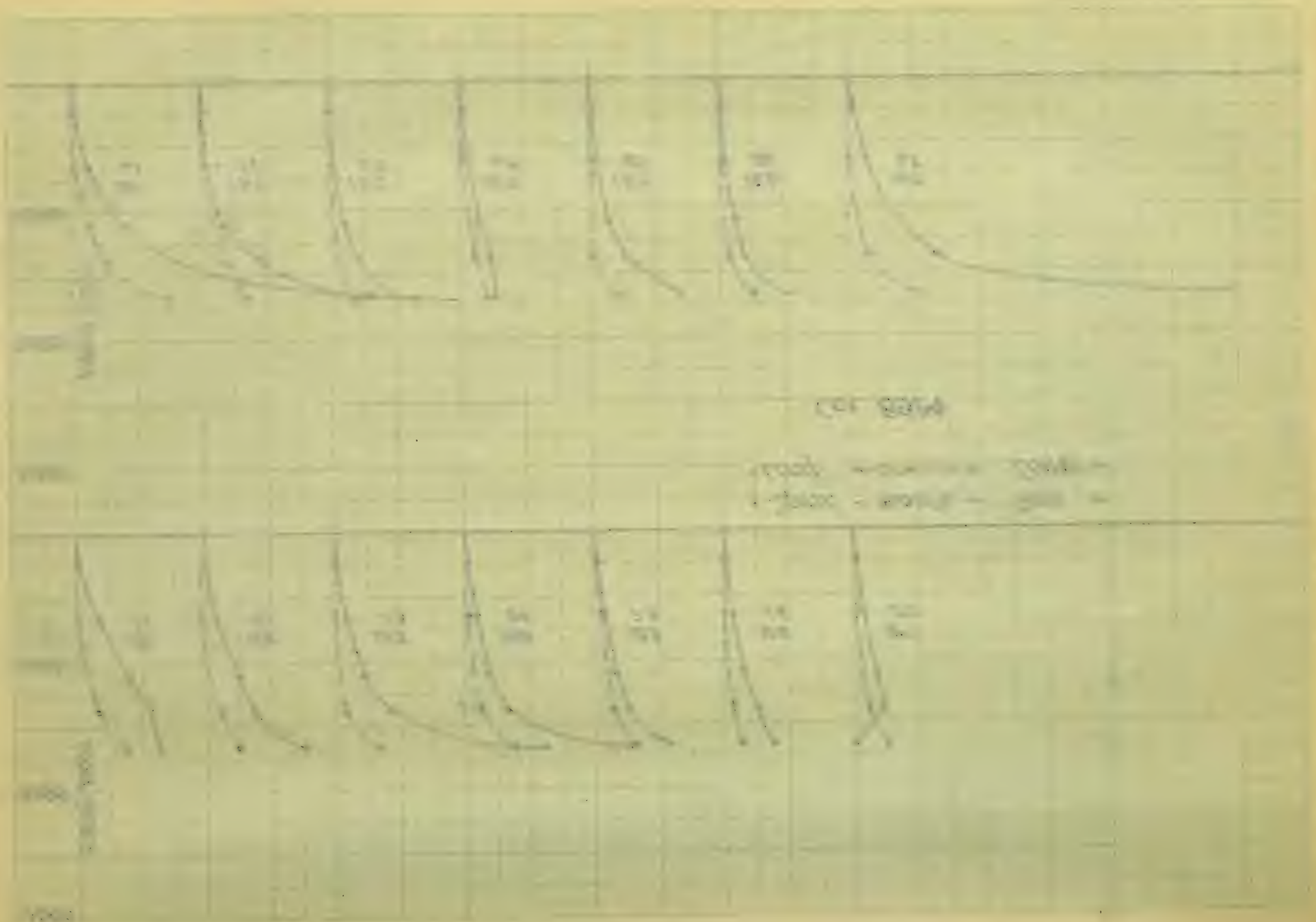


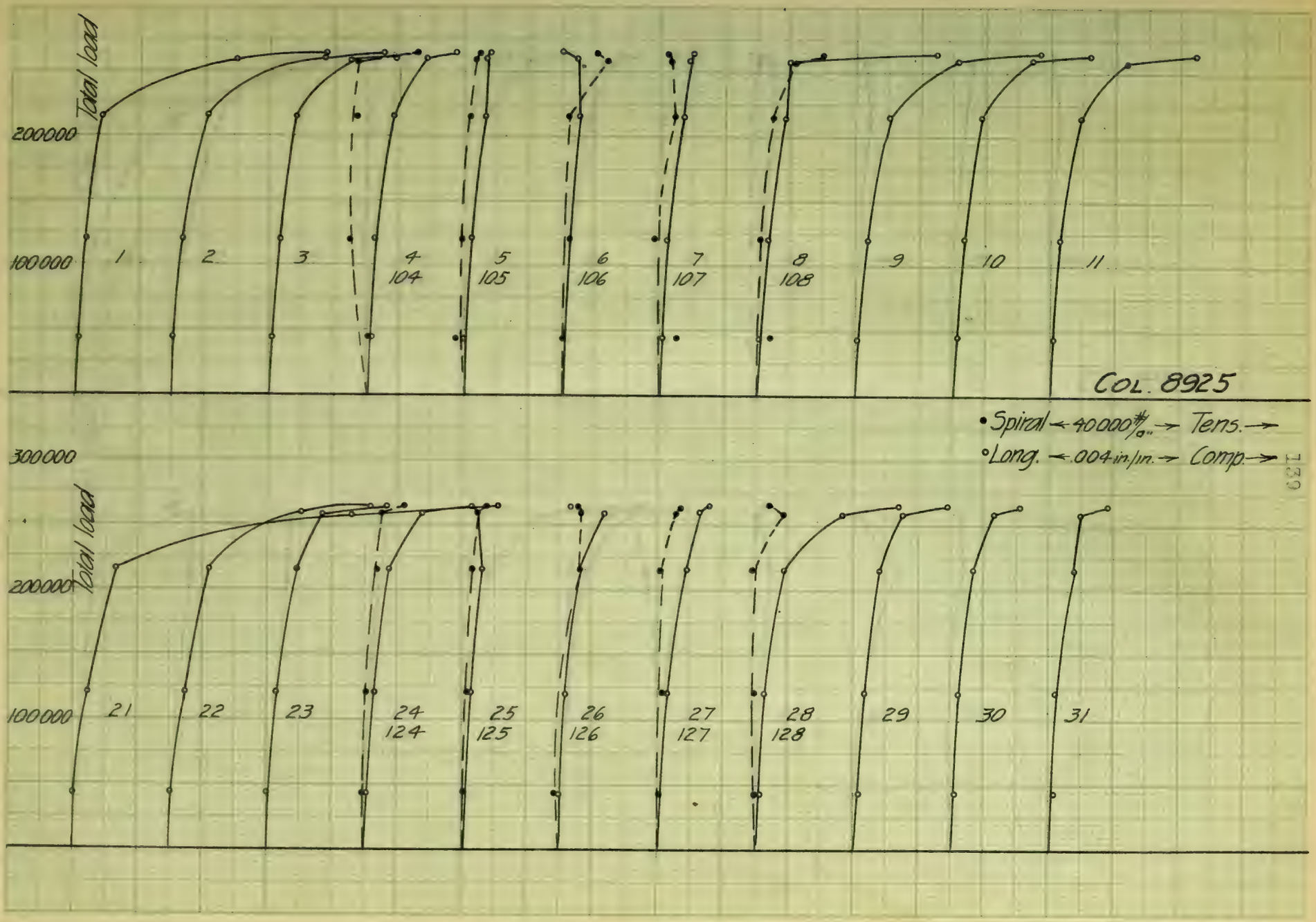

Total Load
100000
56A
56B
C
D
6
56F
G
H
I
56
Total Load
100000
73A
B
C
D
23
73F
G
H
I
73
COL. 8923
40000#/in
Tens.
200000
Total Load
100000
90A
B
C
D
40
90F
G
H
I
90


3000
2000
1000
Unit load
101
1
102
2
103
3
104
4
105
5
106
6
107
7
COL. 8924
• Spiral. ← 40000 #/□" → Tens. →
∘ Long. ← .004 in/in. → Comp. →
3000
2000
1000
Unit load
141
41
142
42
143
43
144
44
145
45
146
46
147
47

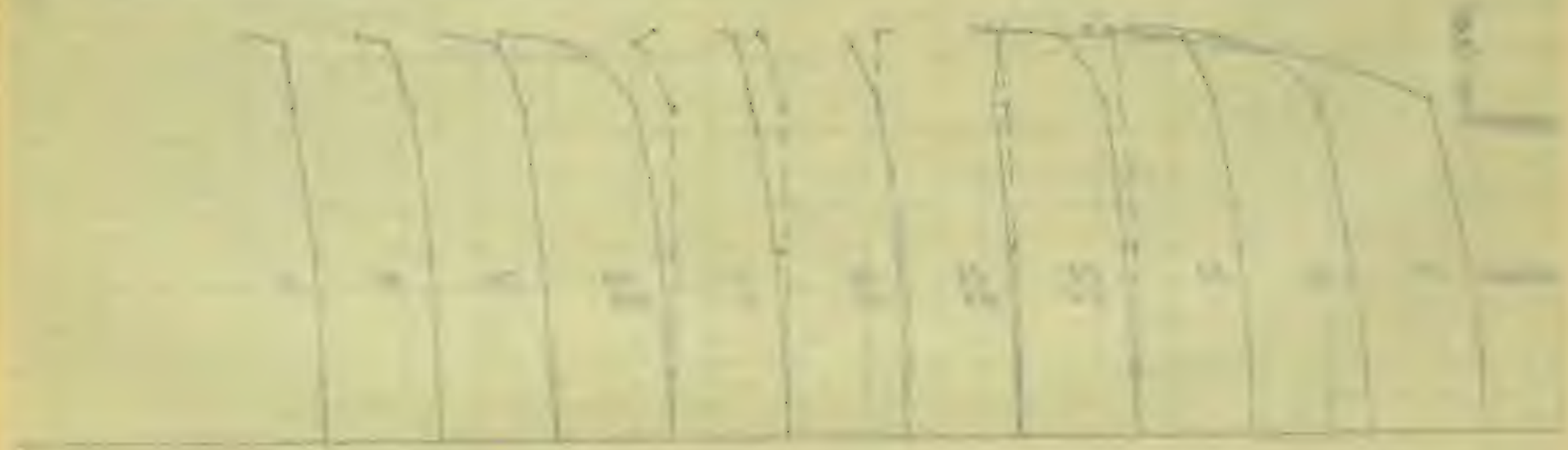


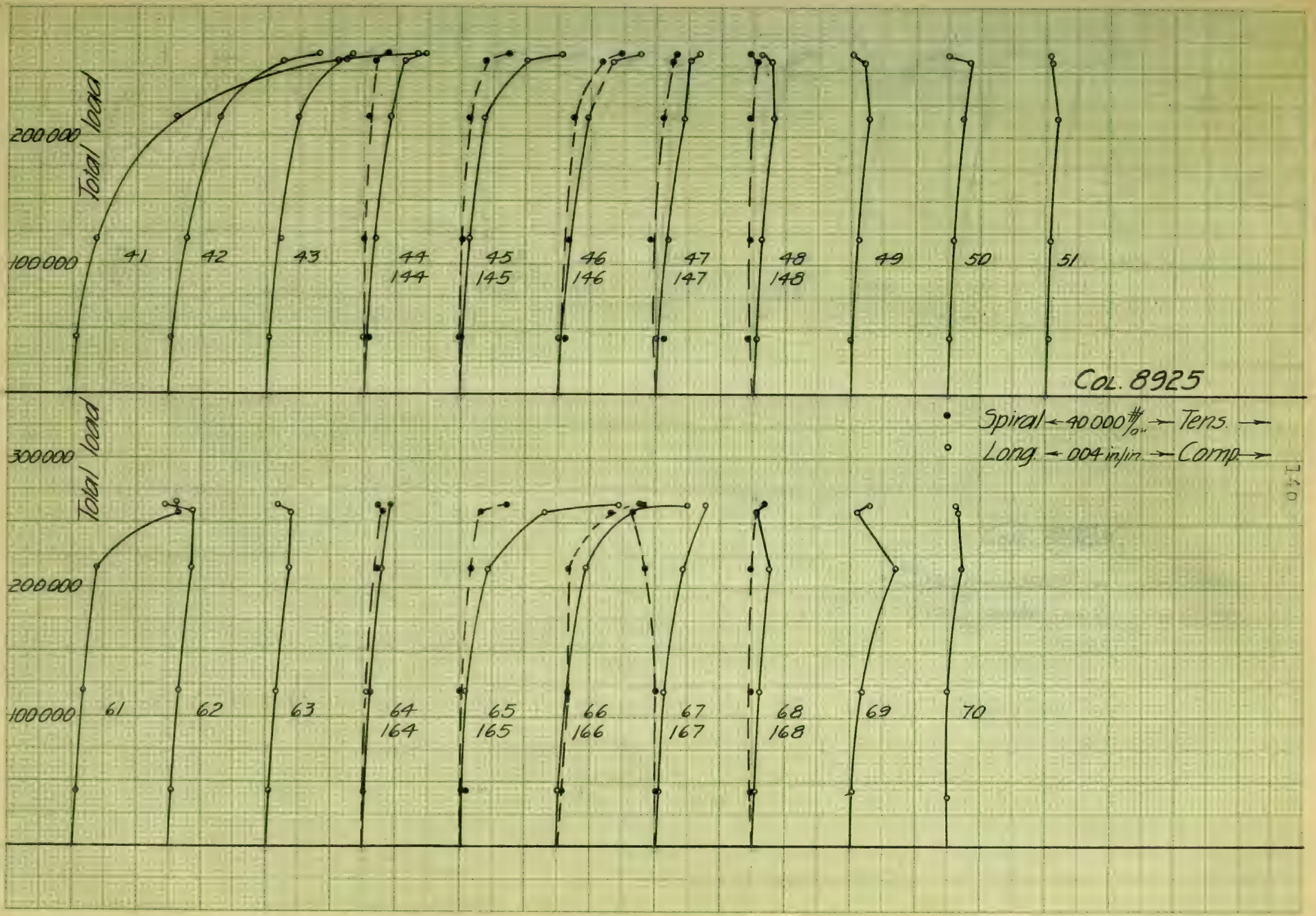

3000
2000
Unit load
1000
121
21
122
22
123
23
124
24
125
25
126
26
127
27
• Spiral ← 40000 #/□" → Tens. →
• Long. ← .004 in./in. → Comp →
3000
COL. 8924
2000
Unit load
1000
161
61
162
62
163
63
164
64
165
65
166
66
167
67



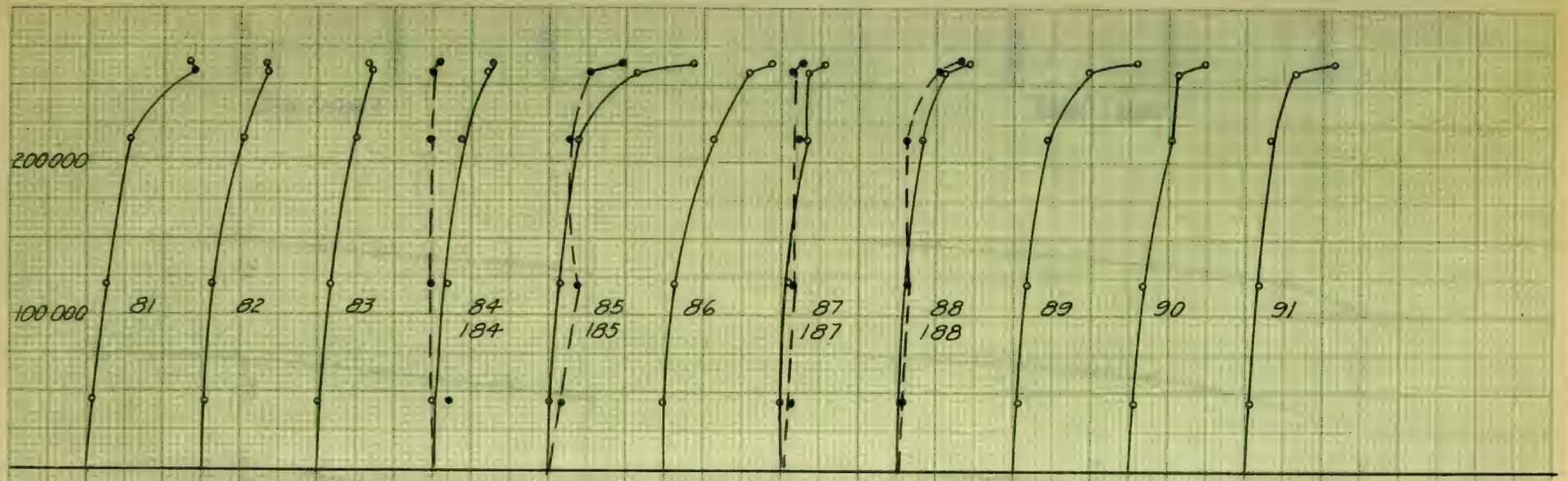

Total load
200000
100000
1
2
3
4
104
5
105
6
106
7
107
8
108
9
10
11
COL. 8925
• Spiral ← 40000 #/□" → Tens. →
° Long. ← .004 in./in. → Comp. →
300000
Total load
200000
100000
21
22
23
24
124
25
125
26
126
27
127
28
128
29
30
31






Total load
200000
100000
41
42
43
44
144
45
145
46
146
47
147
48
148
49
50
51
COL. 8925
Spiral ← 40000 #/in. → Tens.
Long. ← 004 in/in. → Comp.
Total load
300000
200000
100000
61
62
63
64
164
65
165
66
166
67
167
68
168
69
70



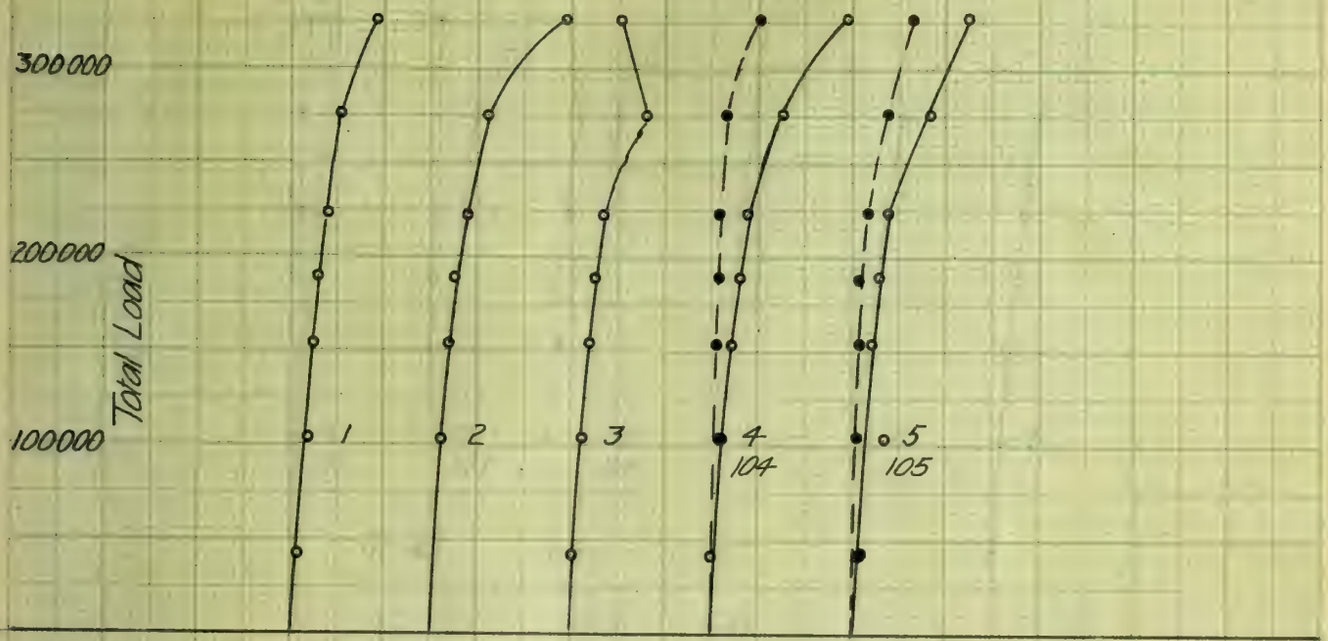


Col. 8925

• Spiral ← 40000 #/□" → → Tens.

° Long. ← .004 in/in. → → Comp.

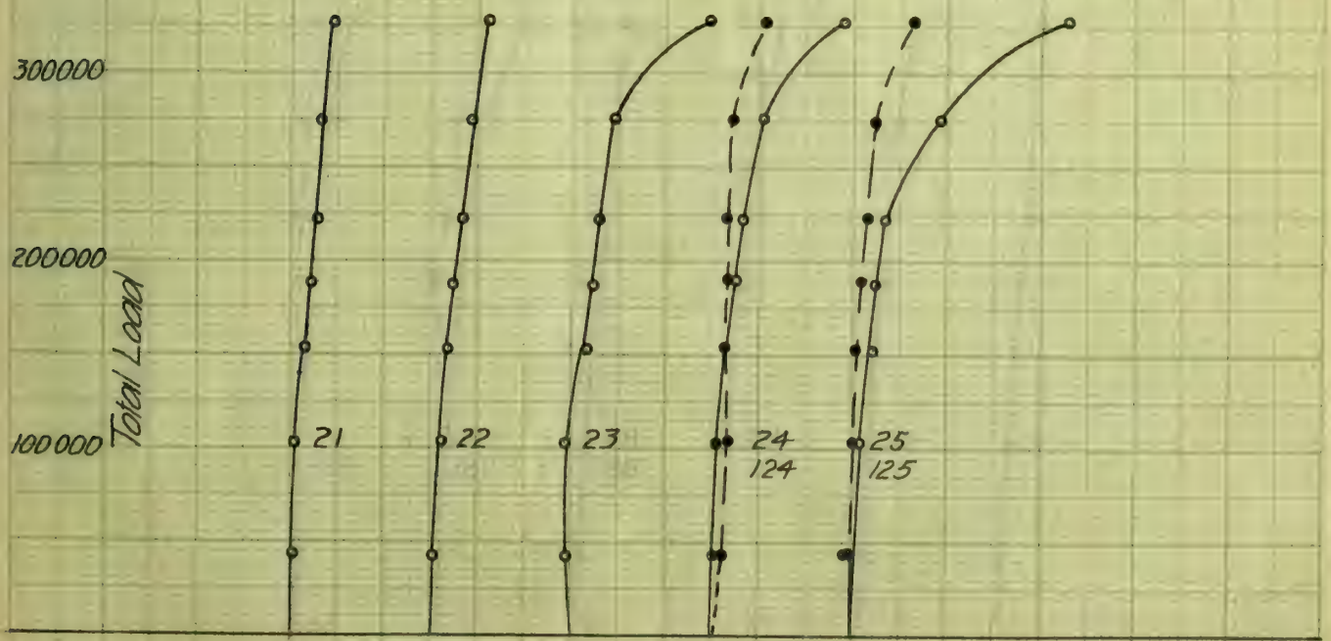




COL. 8926

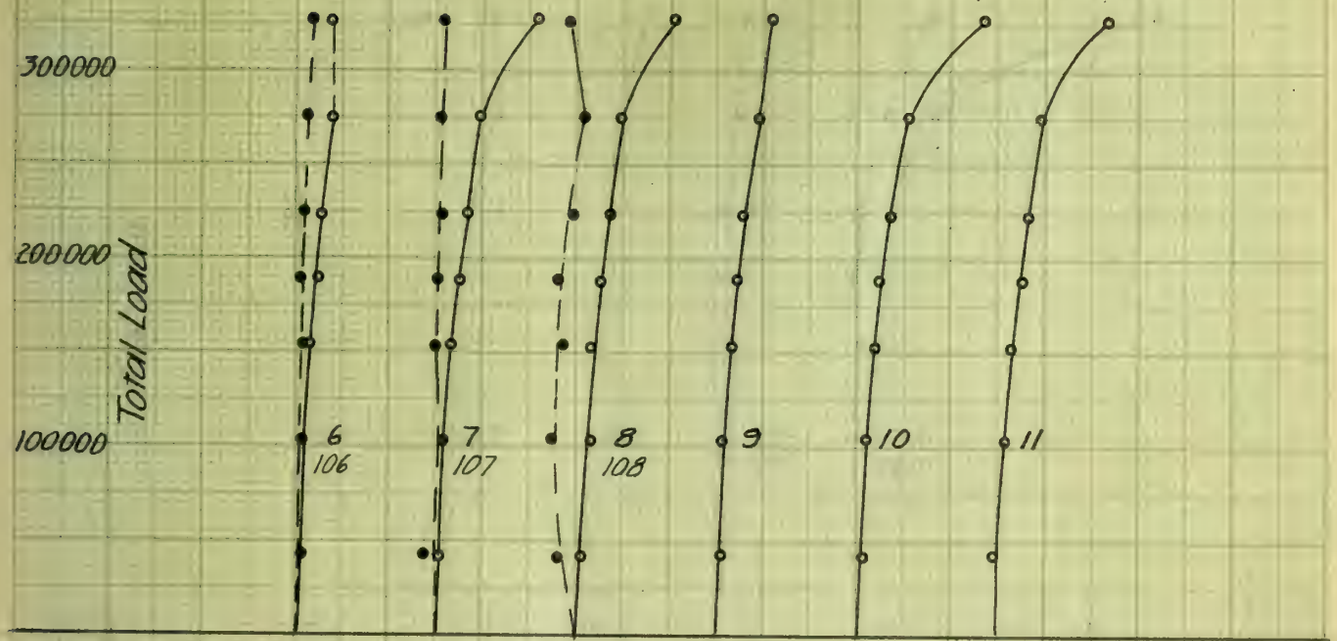
• Spiral ← 40,000 #/□" → Tens. →

○ Long. ← .004 in/in → Comp. →





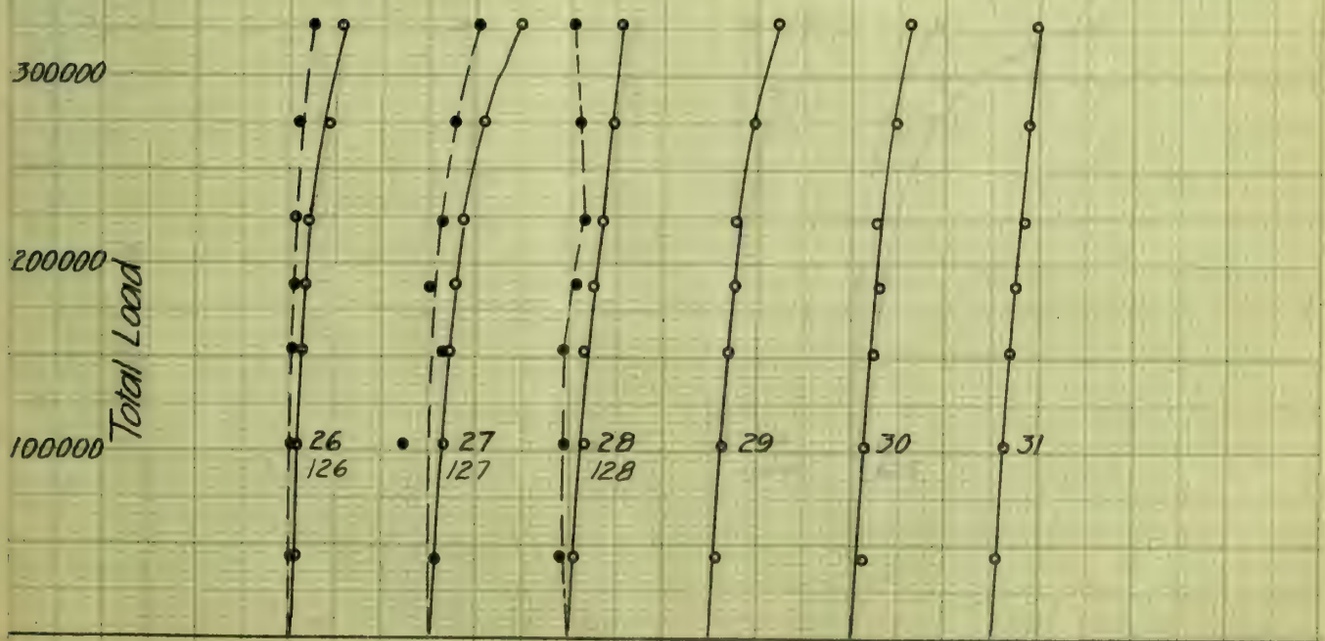




COL. 8926

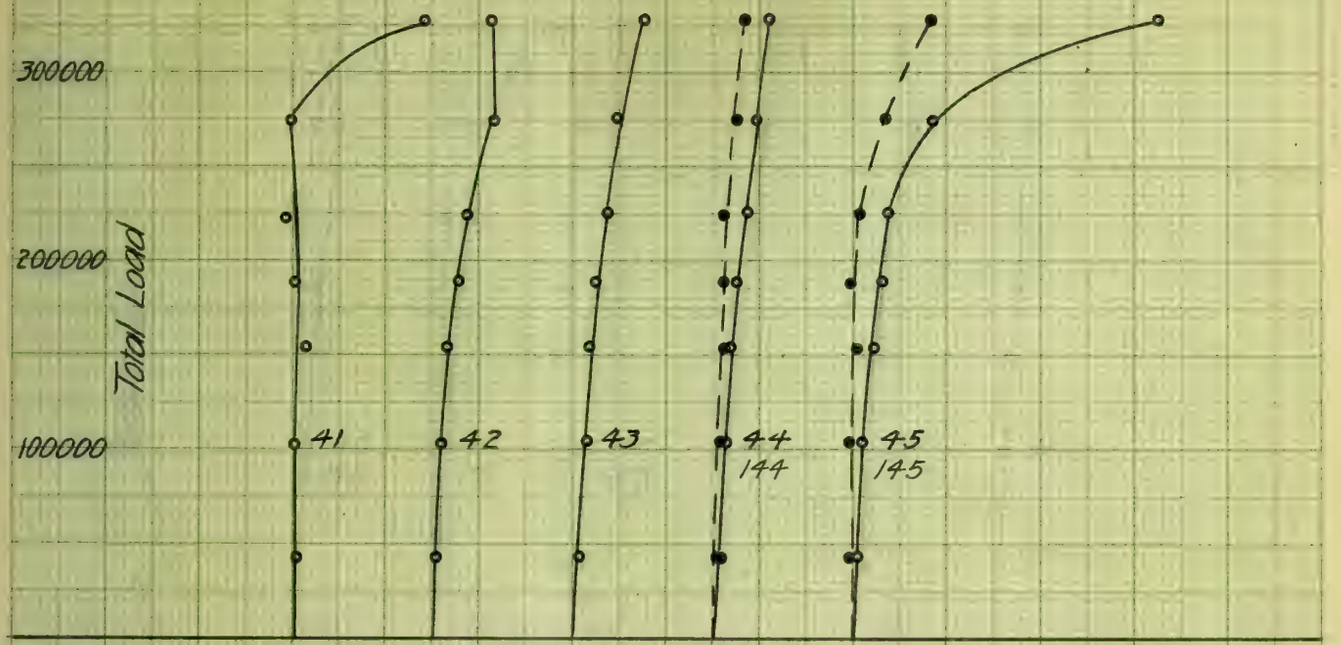
• Spiral ←40 000#/in.→ Tens. →

• Long. ←.004 in/in.→ Comp. →





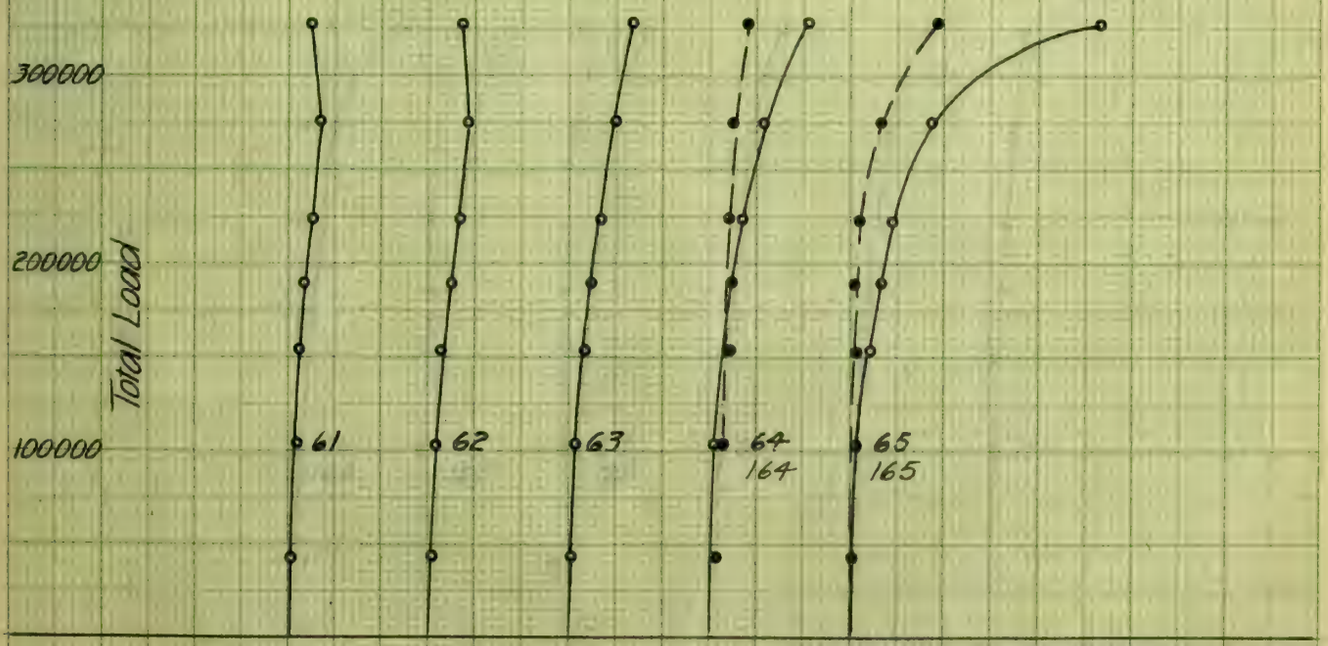




COL. 8926

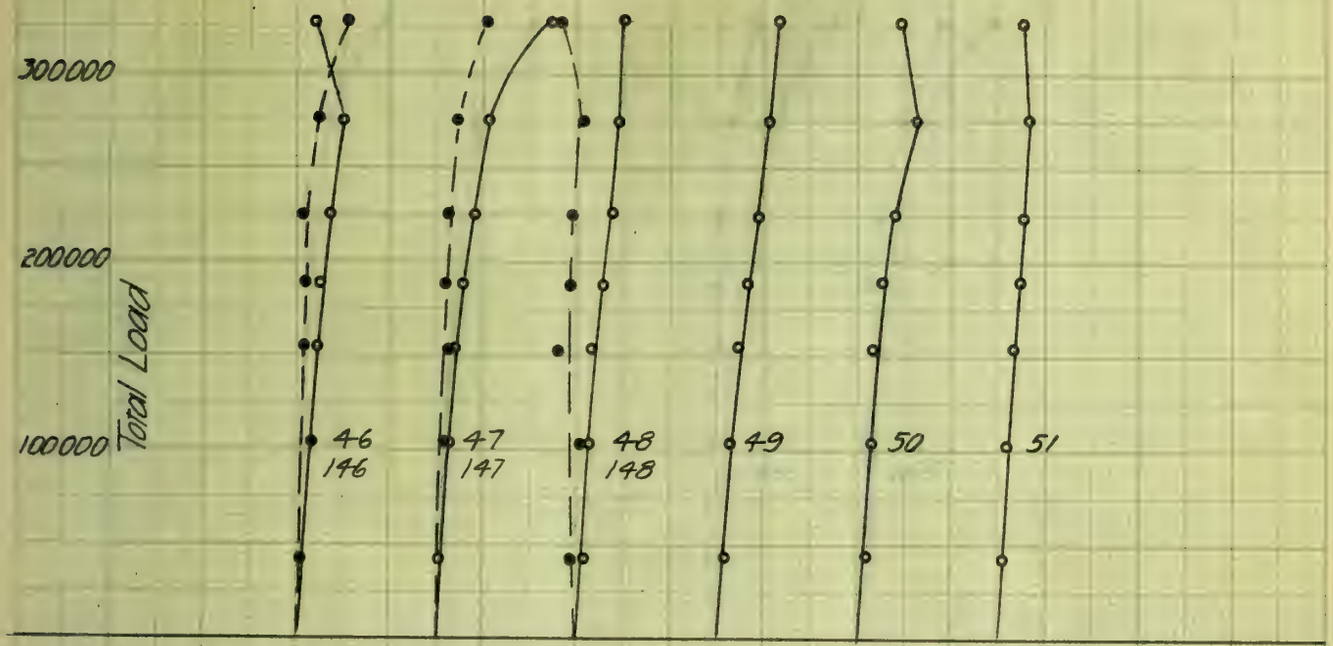
• Spiral ← 40000#/□" → Tens. →

○ Long. ← .0004 in/in. → Comp. →





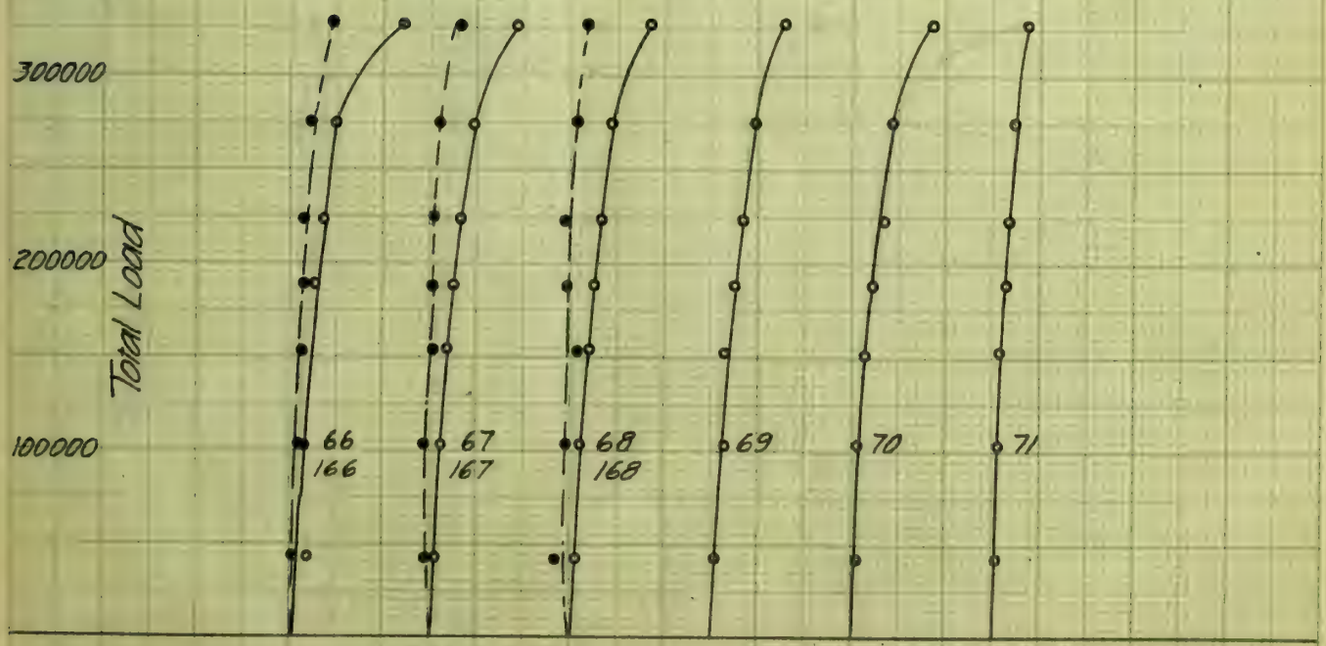




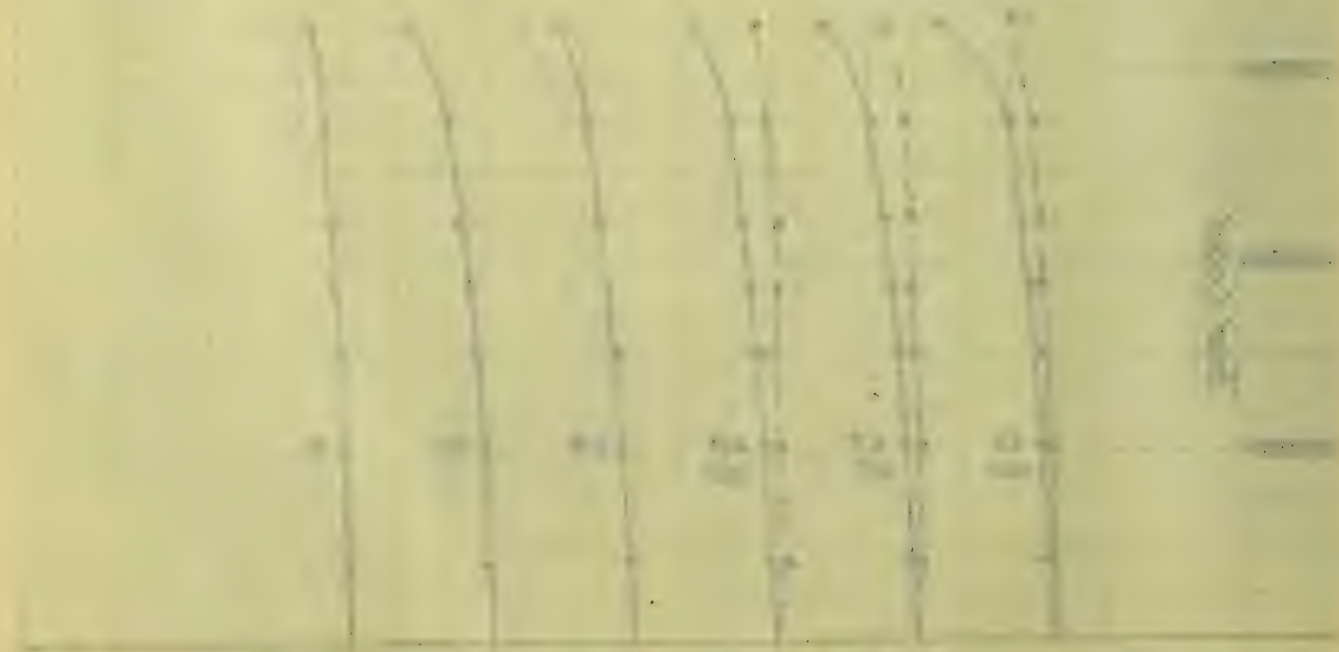
COL. 8926

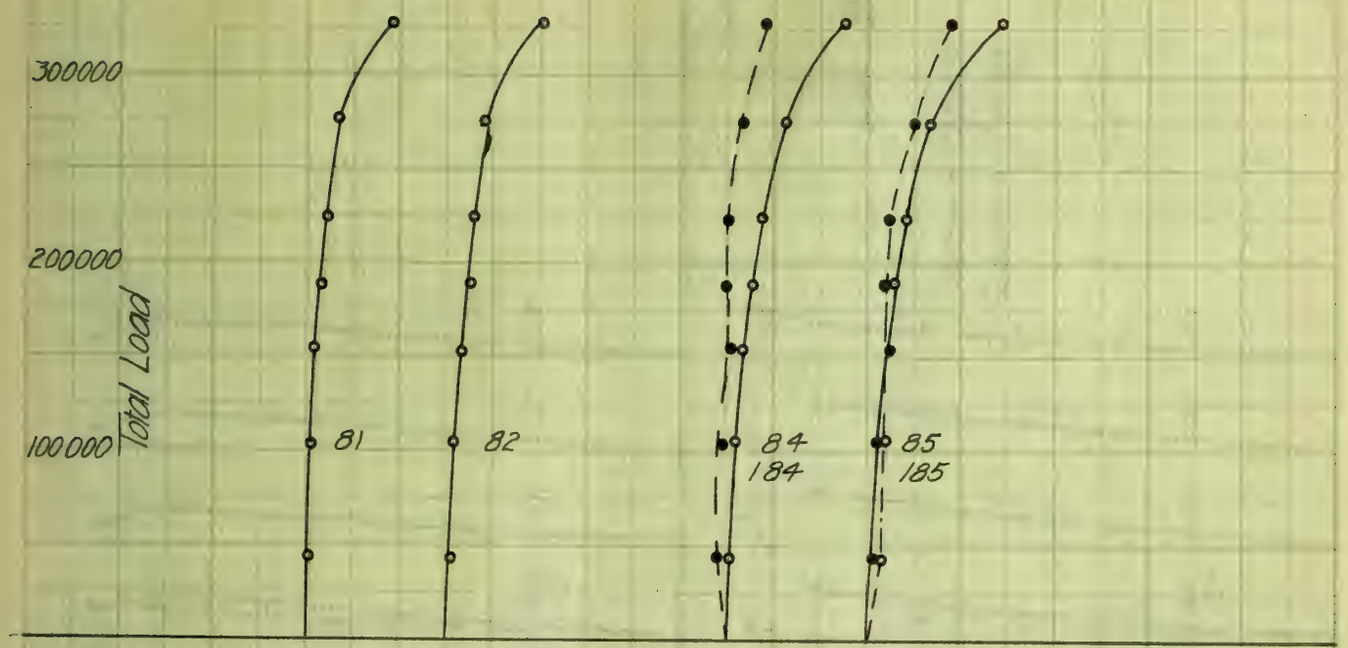
• Spiral ← 40000 #/in. → Tens. →

○ Long. ← .004 in/in → Comp. →





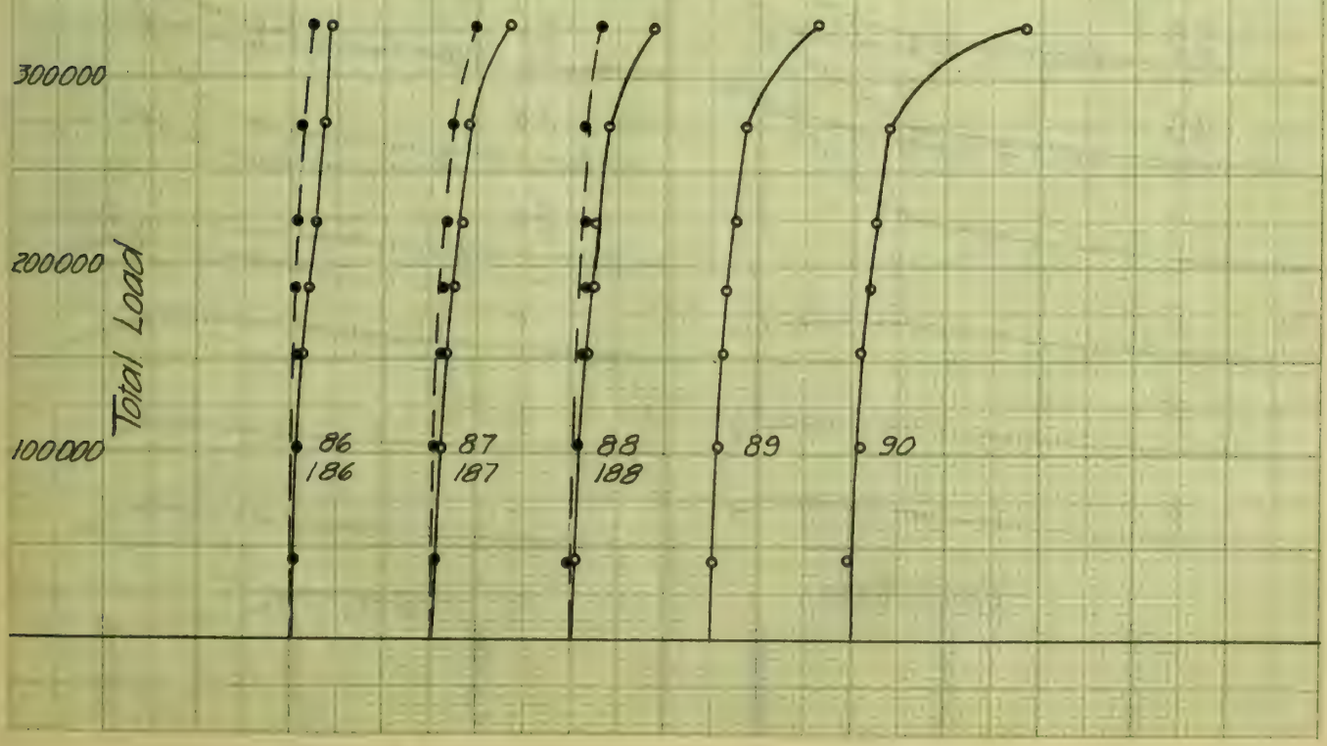




COL. 8926

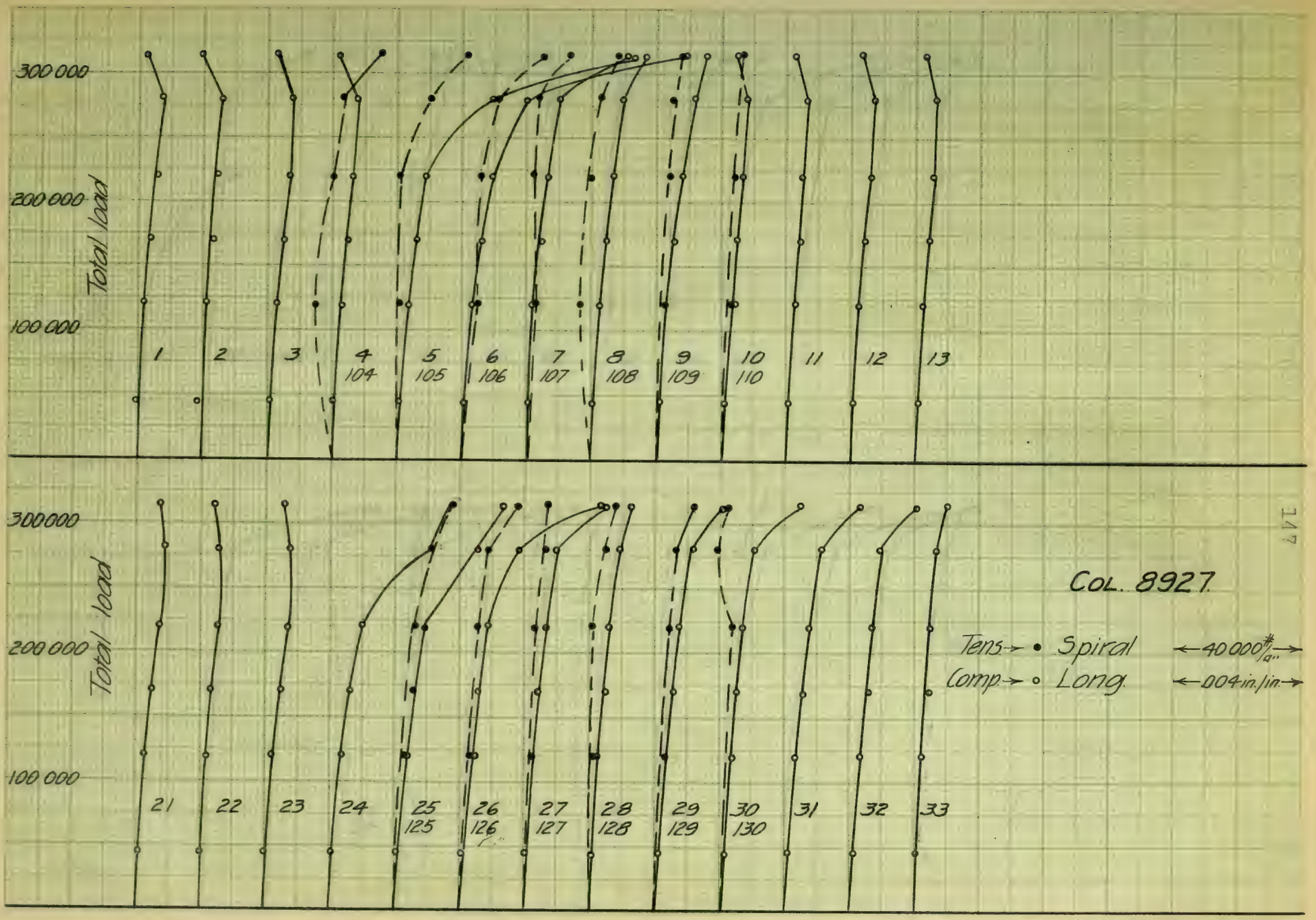
• Spiral ← 40000 #/□" → Tens. →

○ Long. ← .004 in./in. → Comp. →

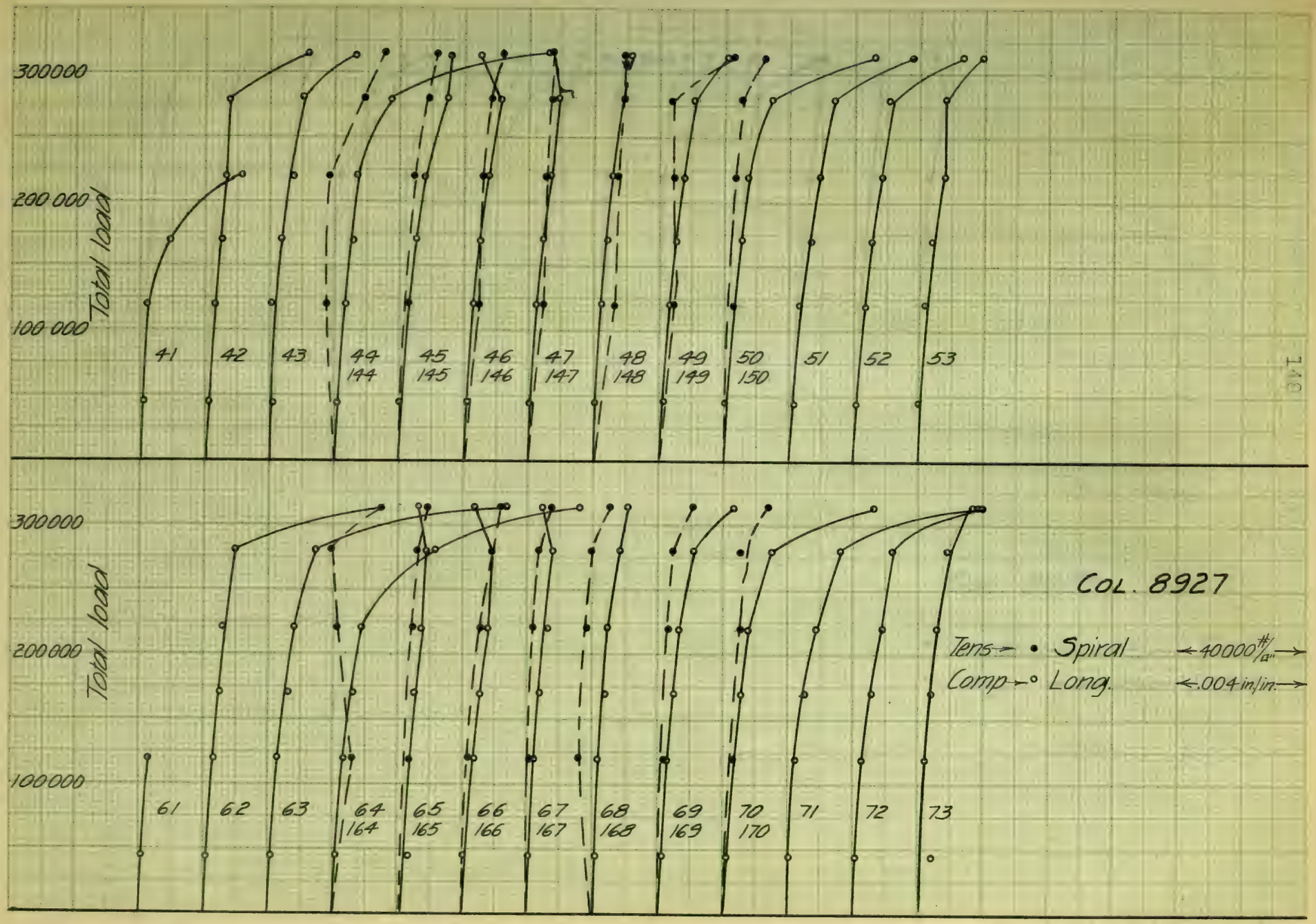


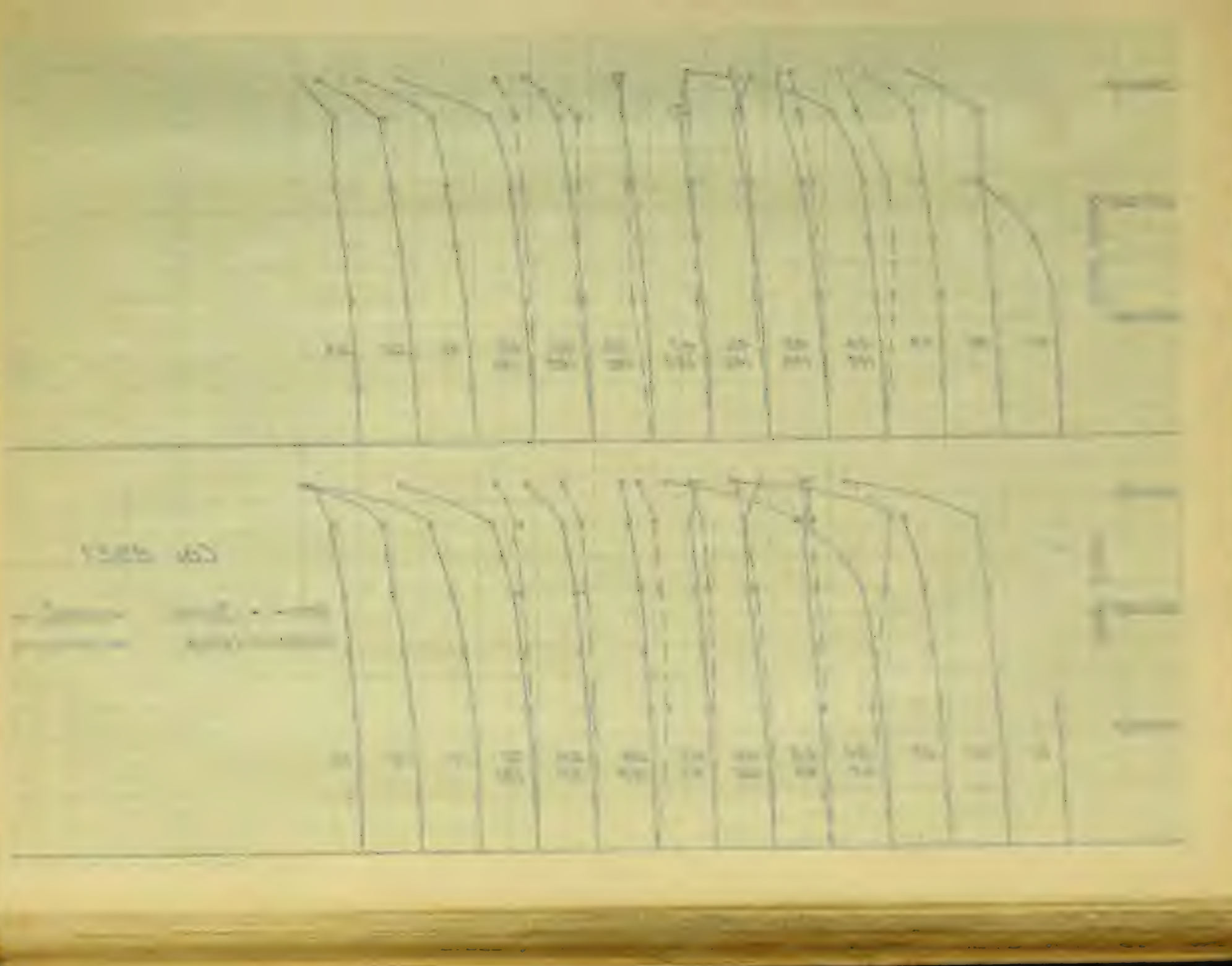


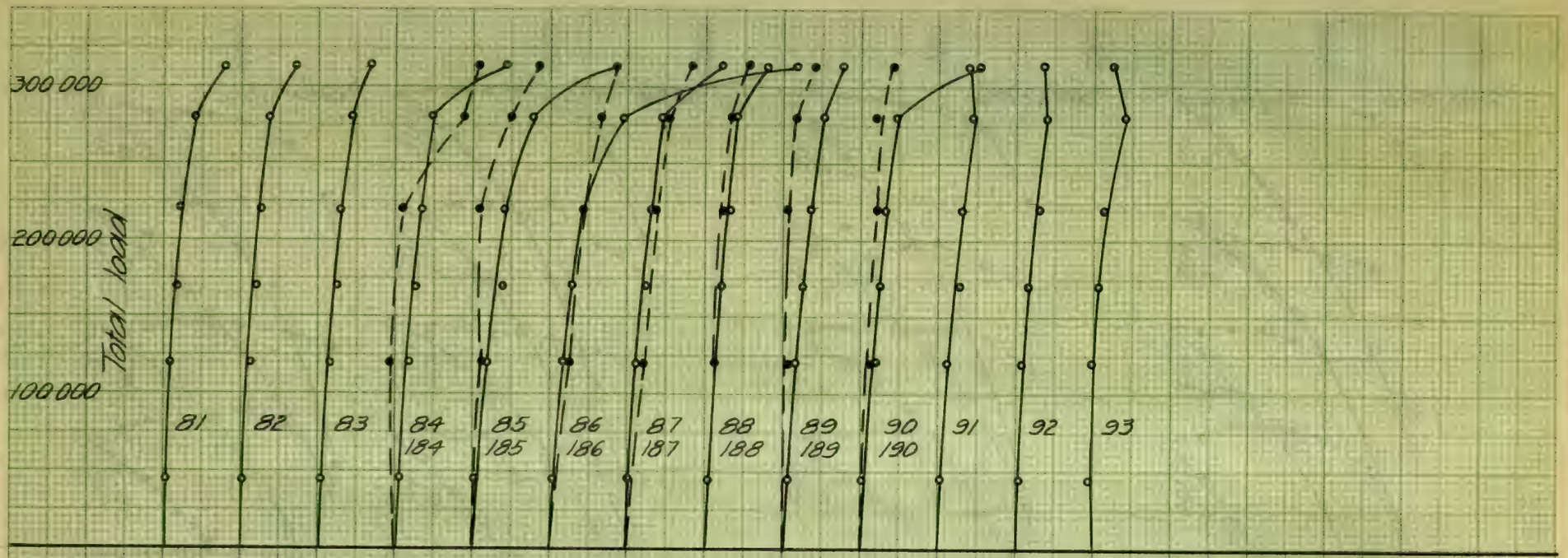



300 000
200 000
100 000
Total load
1
2
3
4
104
5
105
6
106
7
107
8
108
9
109
10
110
11
12
13
300000
200 000
100 000
Total load
21
22
23
24
25
125
26
126
27
127
28
128
29
129
30
130
31
32
33
Col. 8927.
Tens. → • Spiral ← 40 000 #/in²
Comp. → ○ Long. ← .004 in./in.




300000
200000
100000
Total load
41
42
43
44
144
45
145
46
146
47
147
48
148
49
149
50
150
51
52
53
300000
200000
100000
Total load
61
62
63
64
164
65
165
66
166
67
167
68
168
69
169
70
170
71
72
73
COL. 8927
Tens → • Spiral ← 40000 #/in. →
Comp → ° Long. ← .004 in/in. →



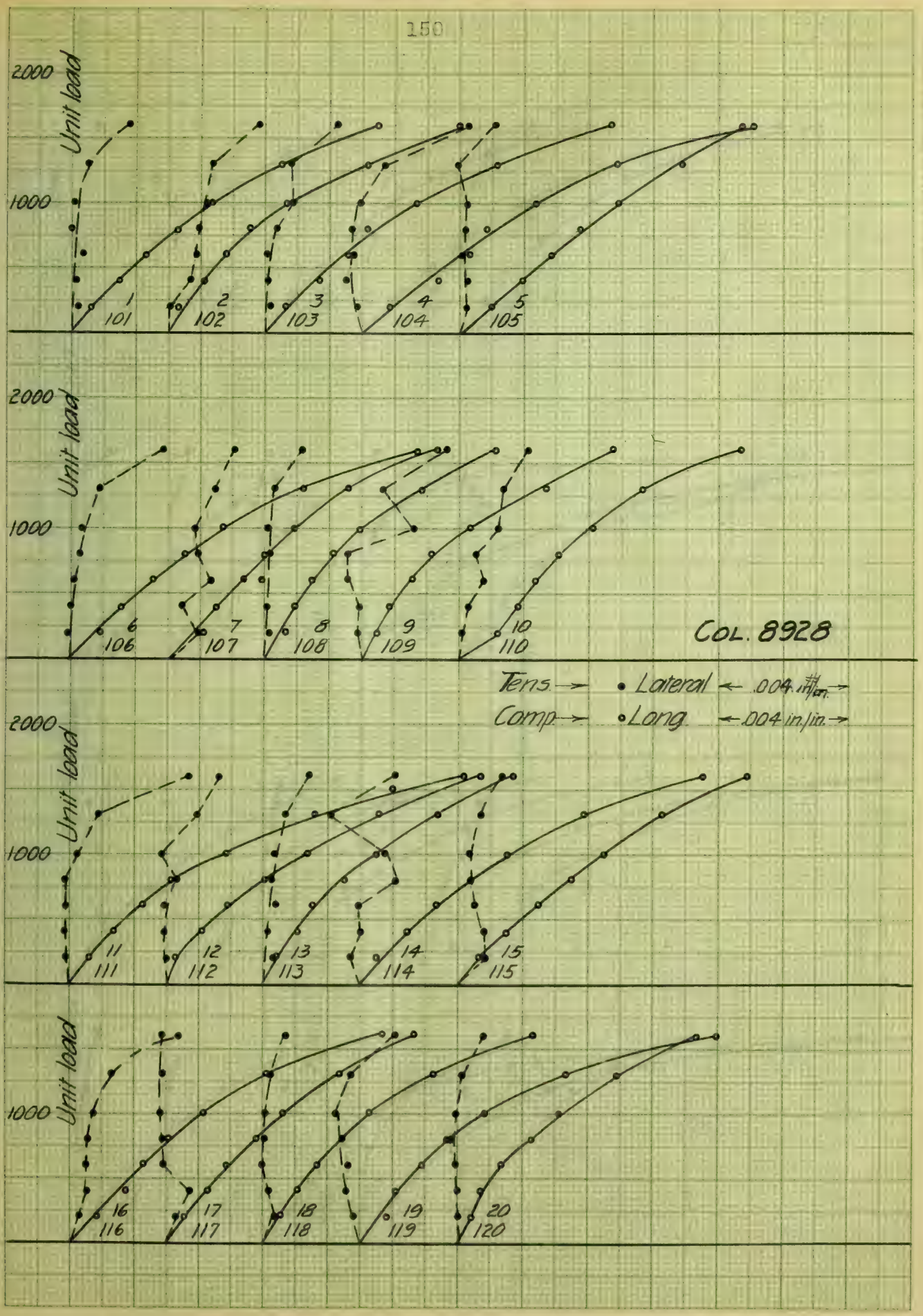


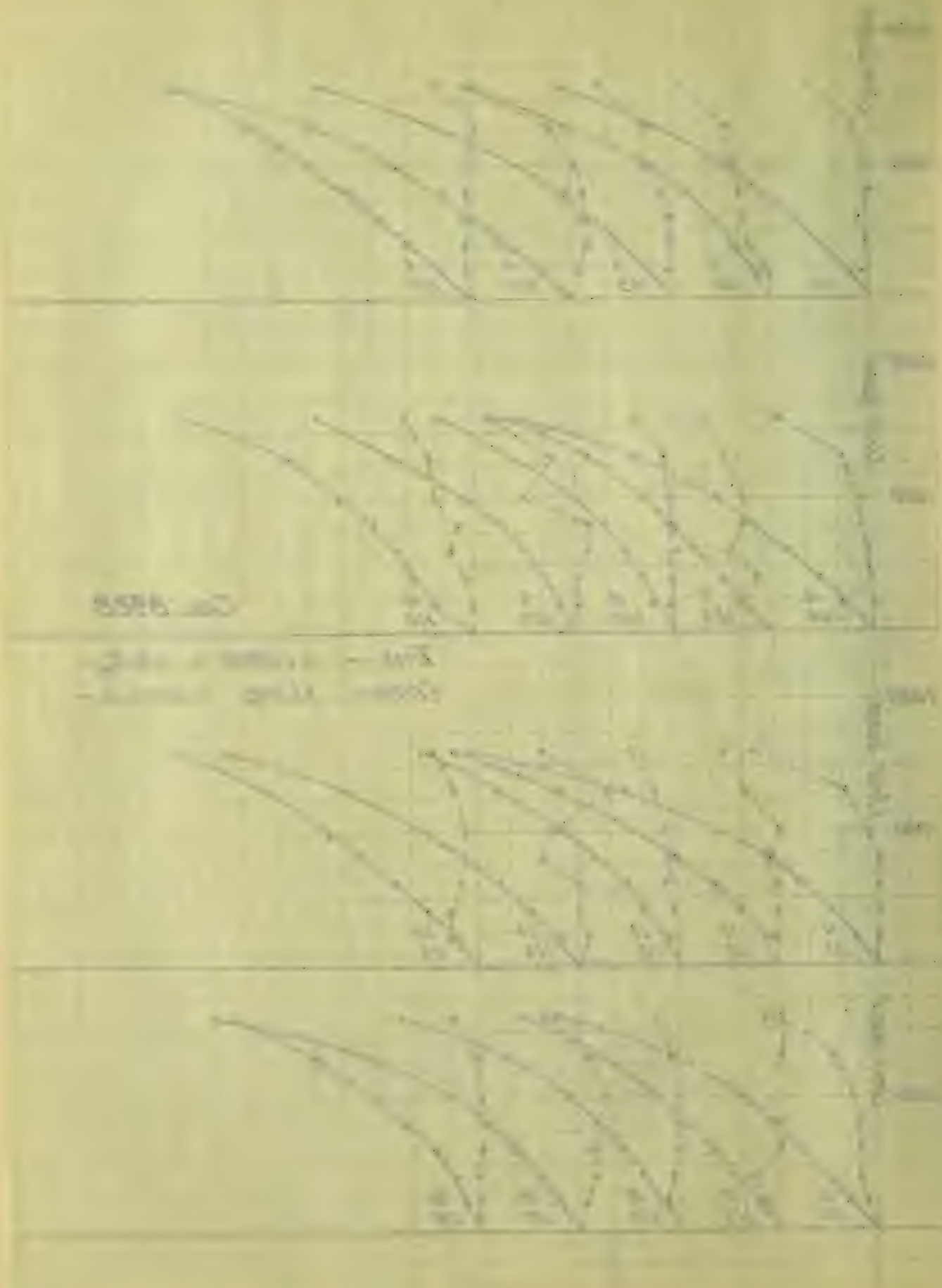
COL. 8927

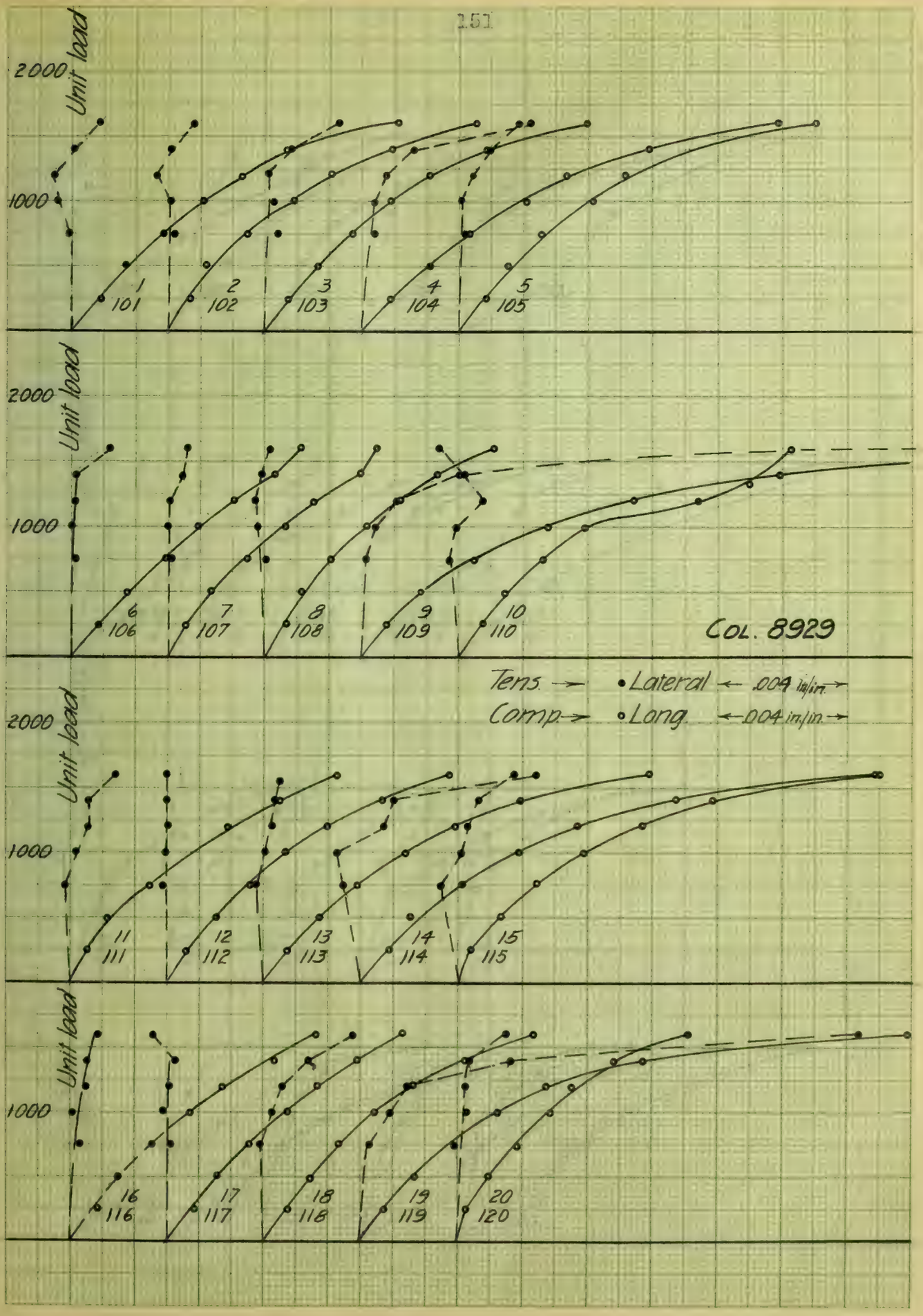
• Spiral ←40000#/in.→ Tens →

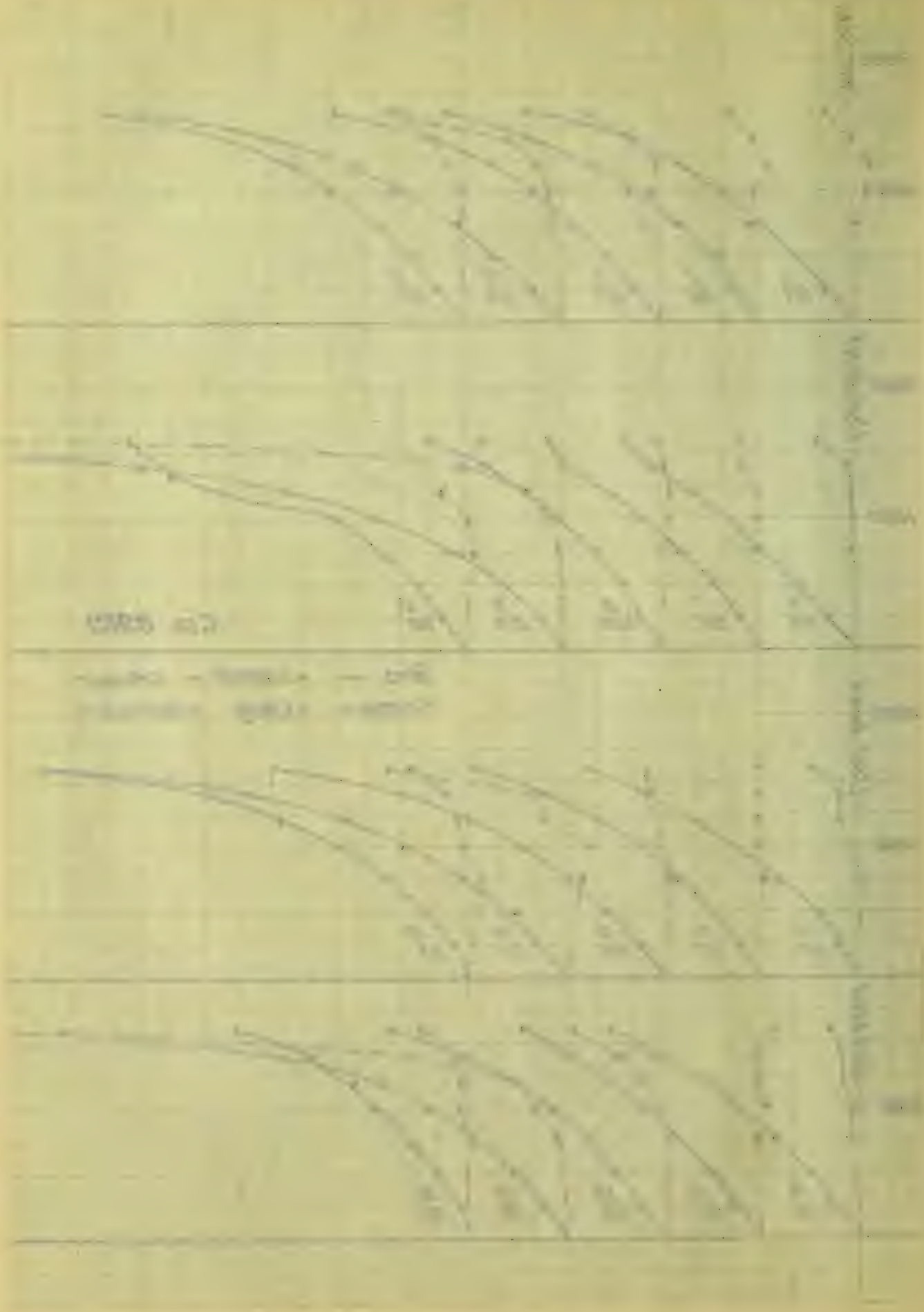
° Long. ←.004 in./in.→ Comp →

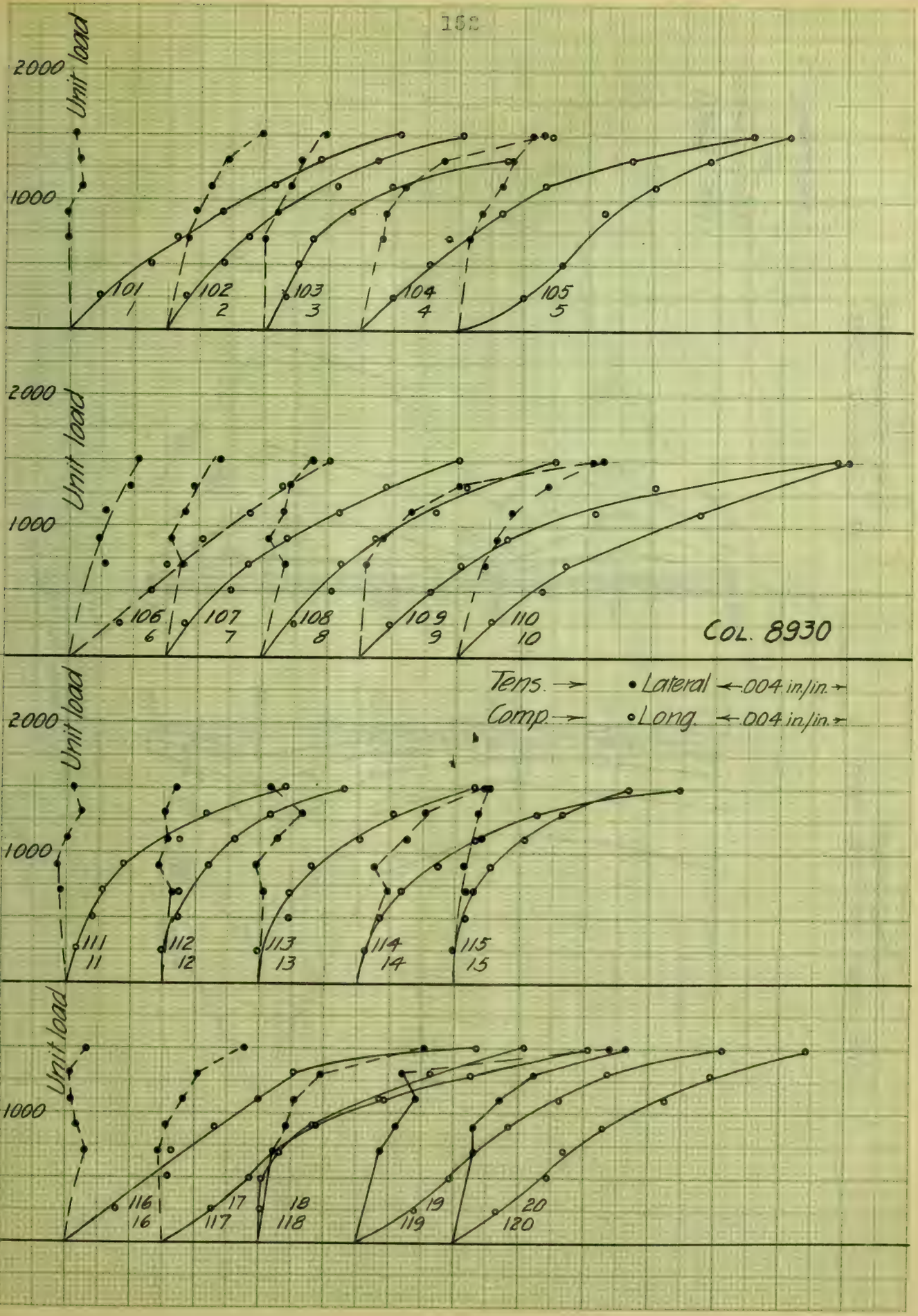


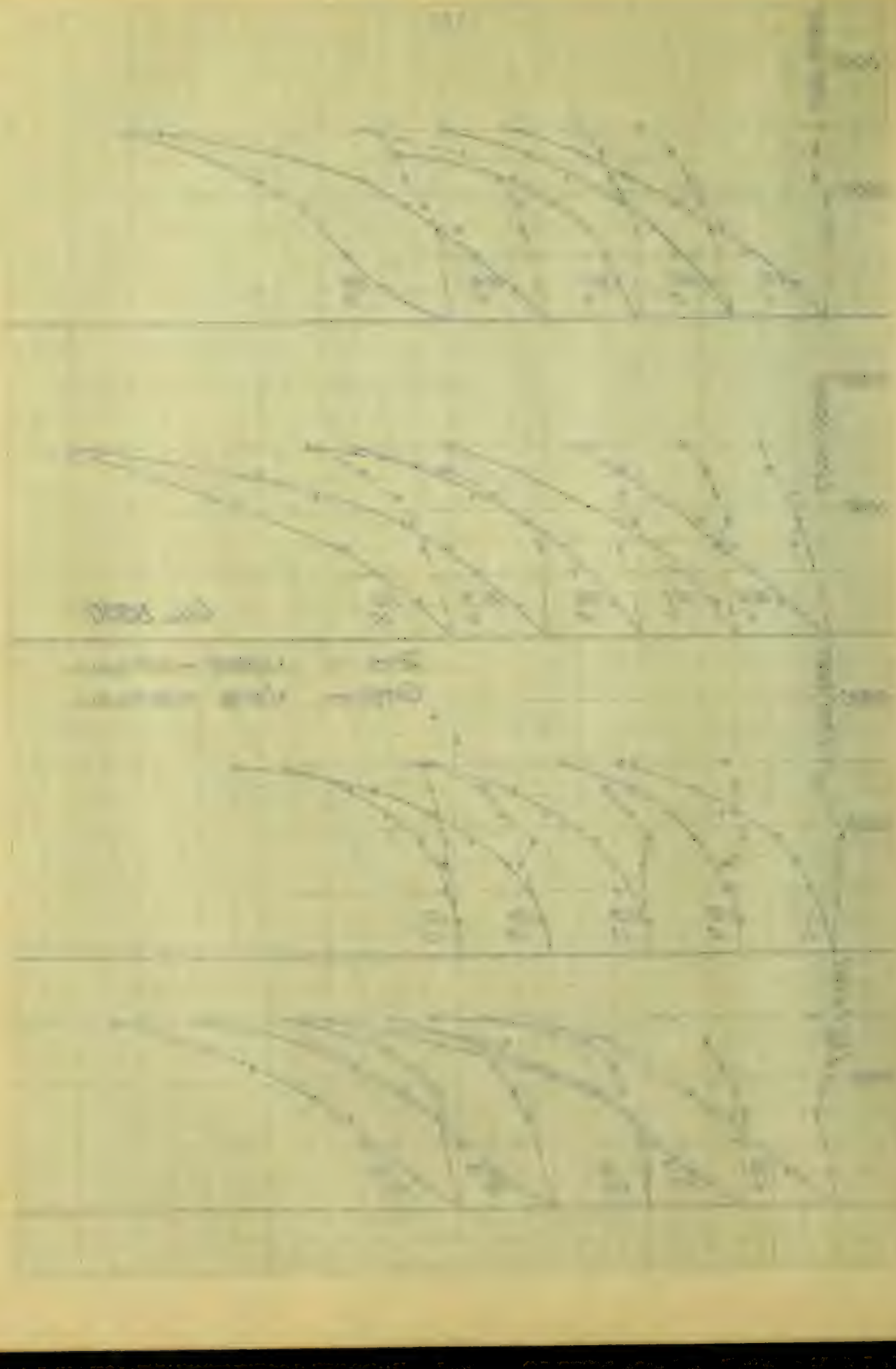

2000
Unit load
1000
1
101
2
102
3
103
4
104
5
105
2000
Unit load
1000
6
106
7
107
8
108
9
109
10
110
COL. 8928
Tens → • Lateral ← .004 in/in →
Comp → • Long. ← .004 in/in →
2000
Unit load
1000
11
111
12
112
13
113
14
114
15
115
Unit load
1000
16
116
17
117
18
118
19
119
20
120

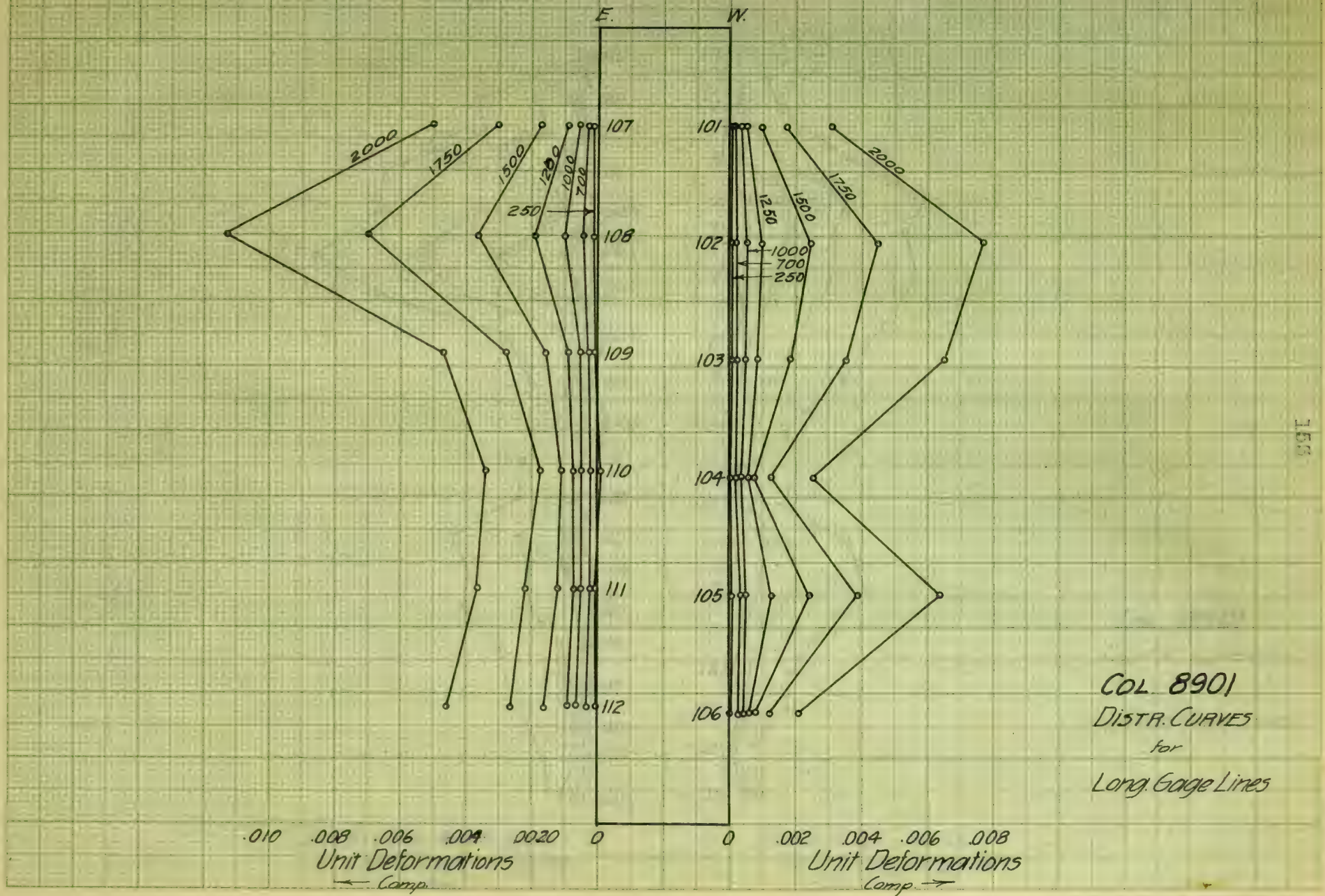



2000
Unit load
1000
1
101
2
102
3
103
4
104
5
105
2000
Unit load
1000
6
106
7
107
8
108
9
109
10
110
COL. 8929
Tens. → • Lateral ← .004 in/in →
Comp. → ○ Long. ← .004 in/in →
2000
Unit load
1000
11
111
12
112
13
113
14
114
15
115
Unit load
1000
16
116
17
117
18
118
19
119
20
120

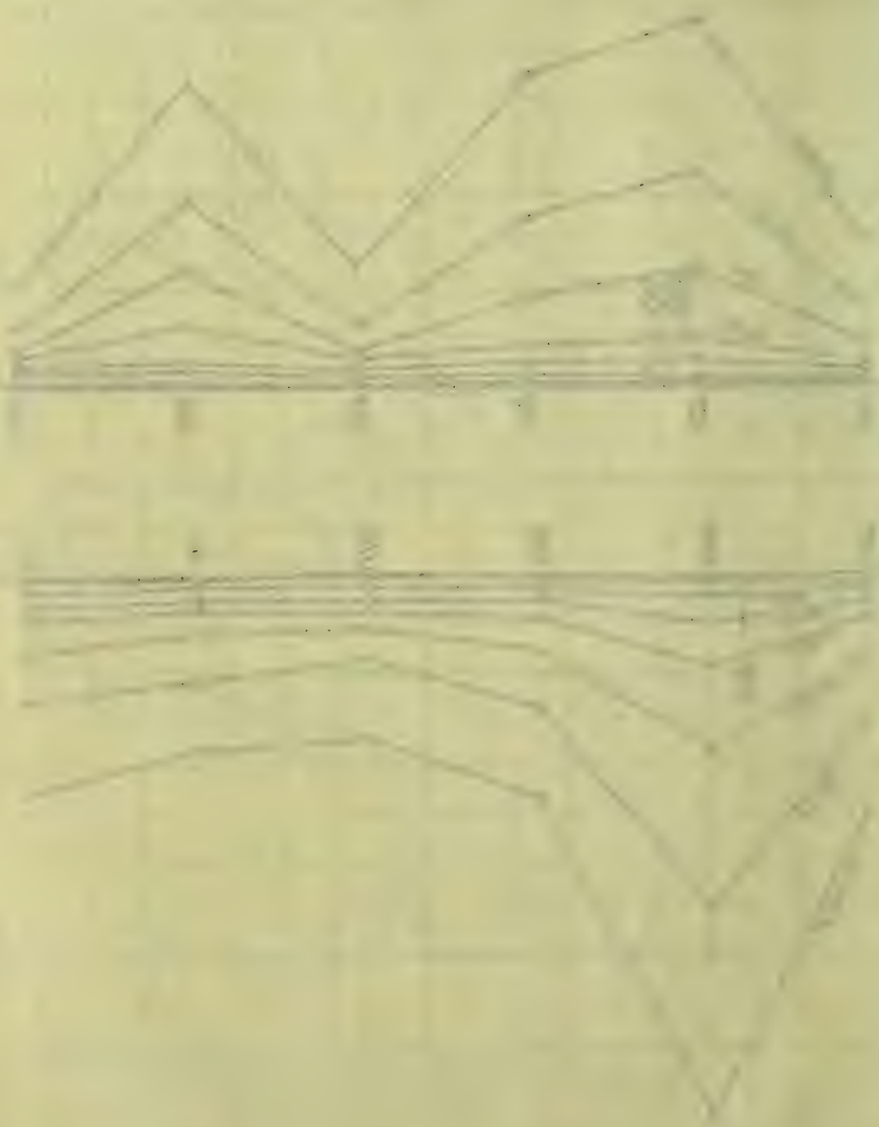


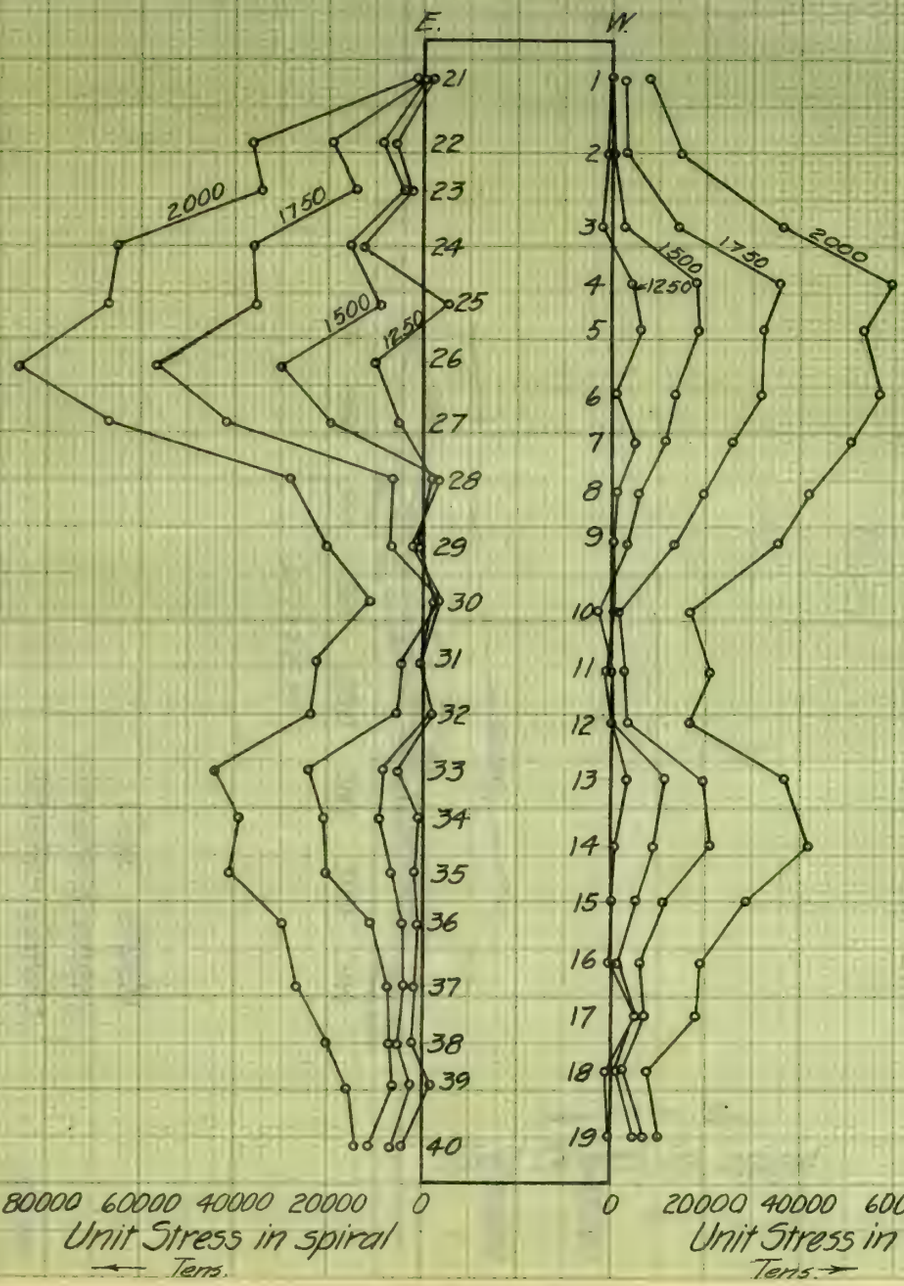

2000
Unit load
1000
101
1
102
2
103
3
104
4
105
5
2000
Unit load
1000
106
6
107
7
108
8
109
9
110
10
COL. 8930
Tens. → • Lateral ← .004 in./in. →
Comp. → ○ Long. ← .004 in./in. →
2000
Unit load
1000
111
11
112
12
113
13
114
14
115
15
Unit load
1000
116
16
17
117
18
118
19
119
20
120



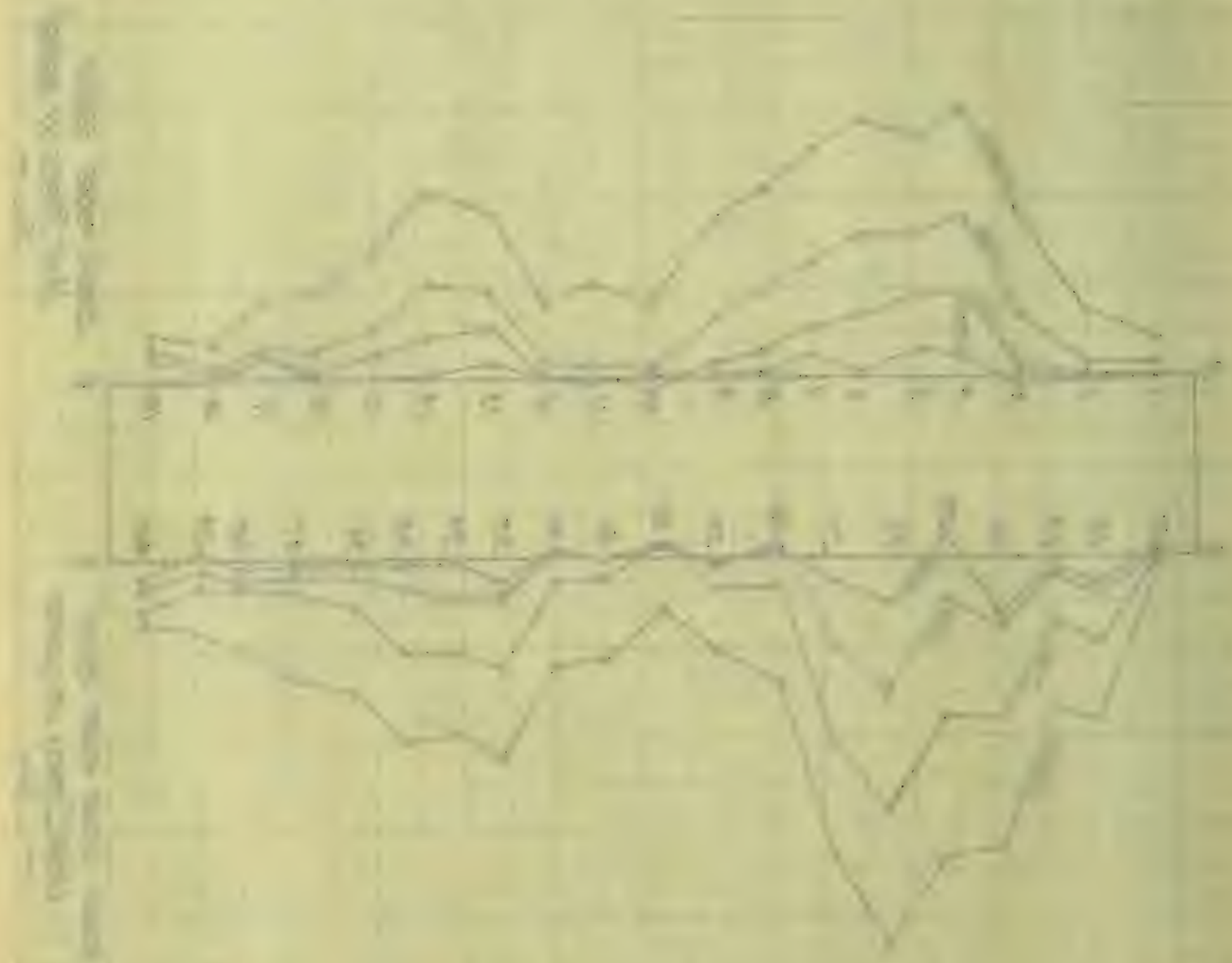


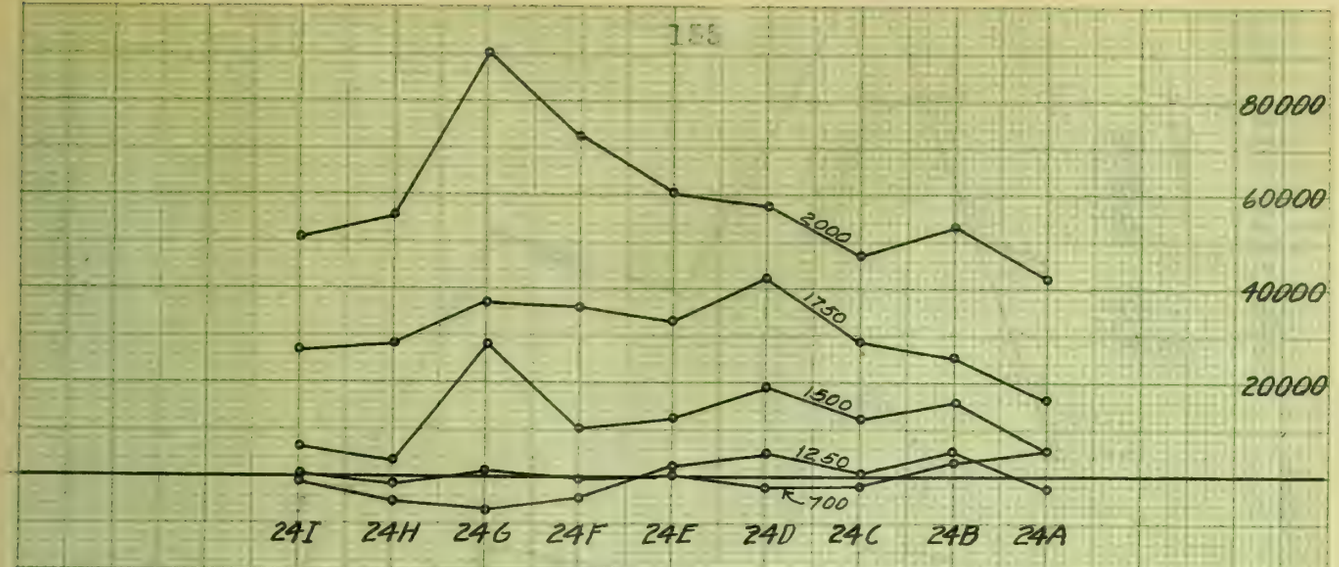
COL 8901
DISTR. CURVES
for
Long. Gage Lines



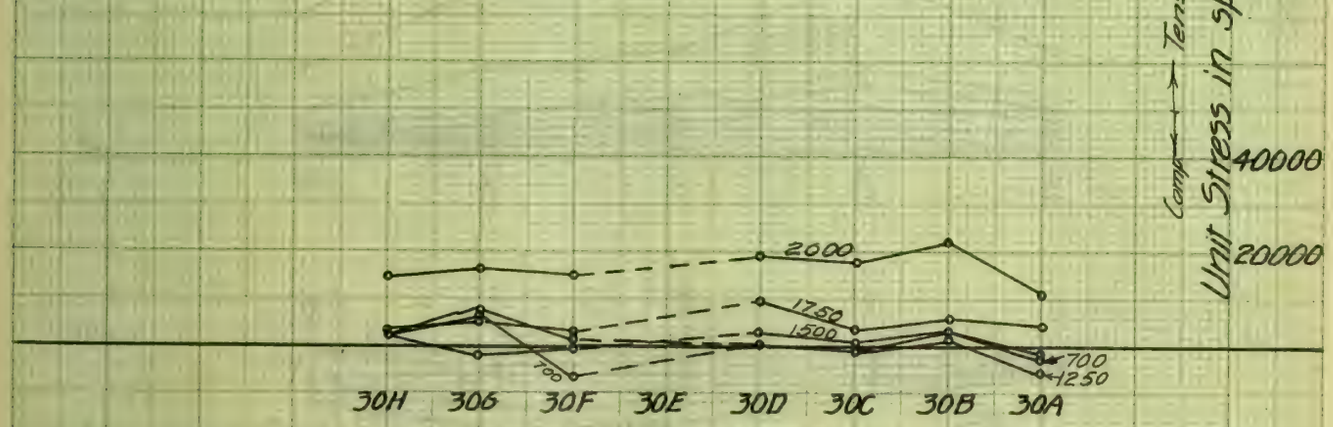


COL. 8901
DISTR. CURVES
for
Spiral Gage Lines.



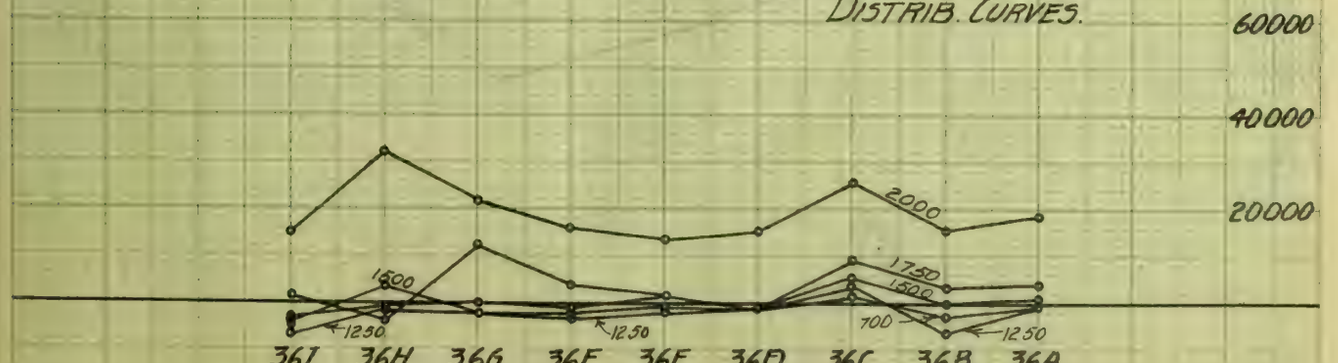


TOP



CENTER

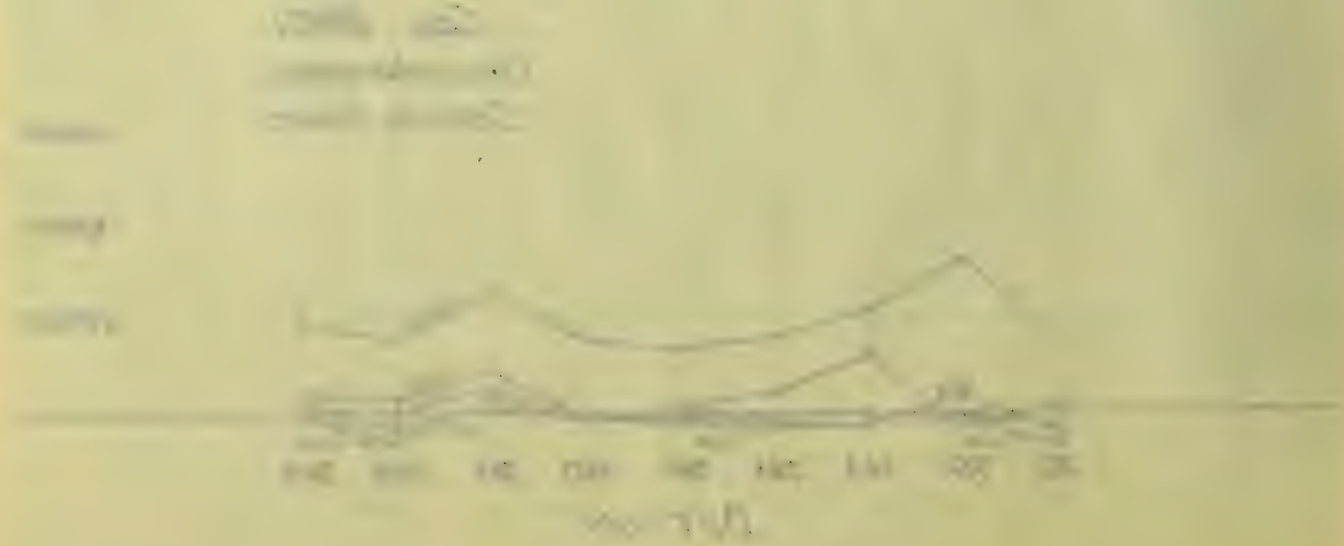
COL. 8901
Circumferential
DISTRIB. CURVES.

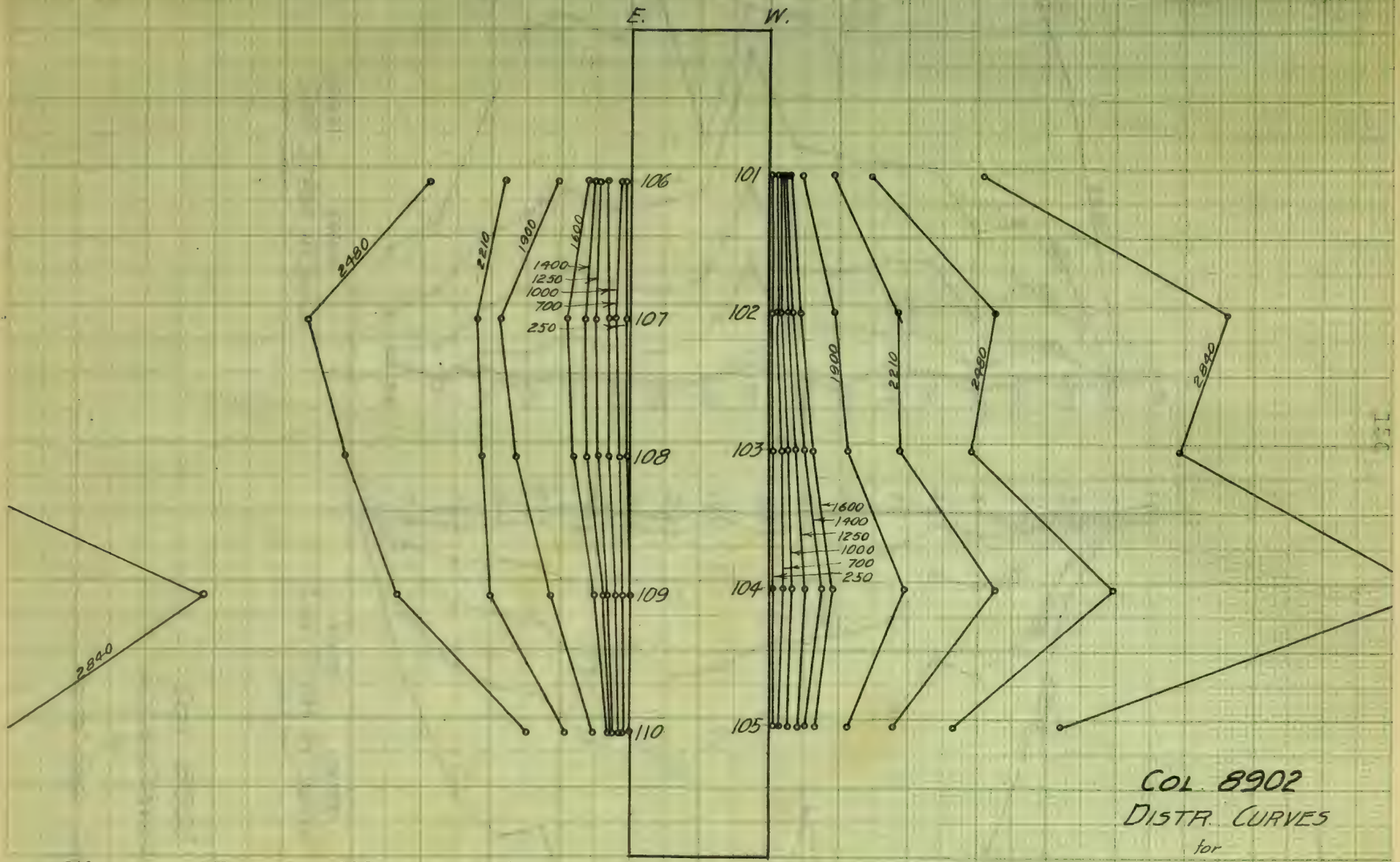


BOTTOM



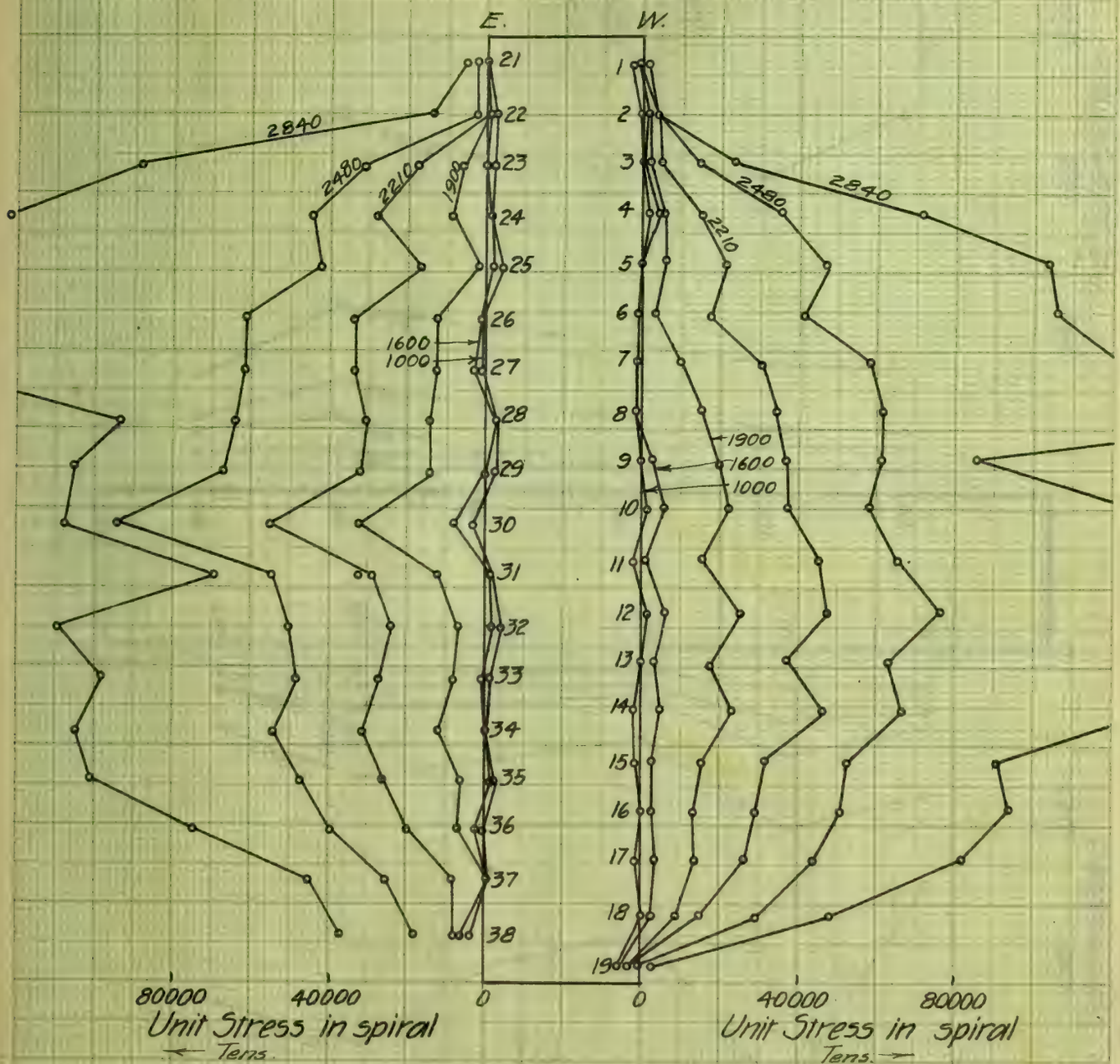






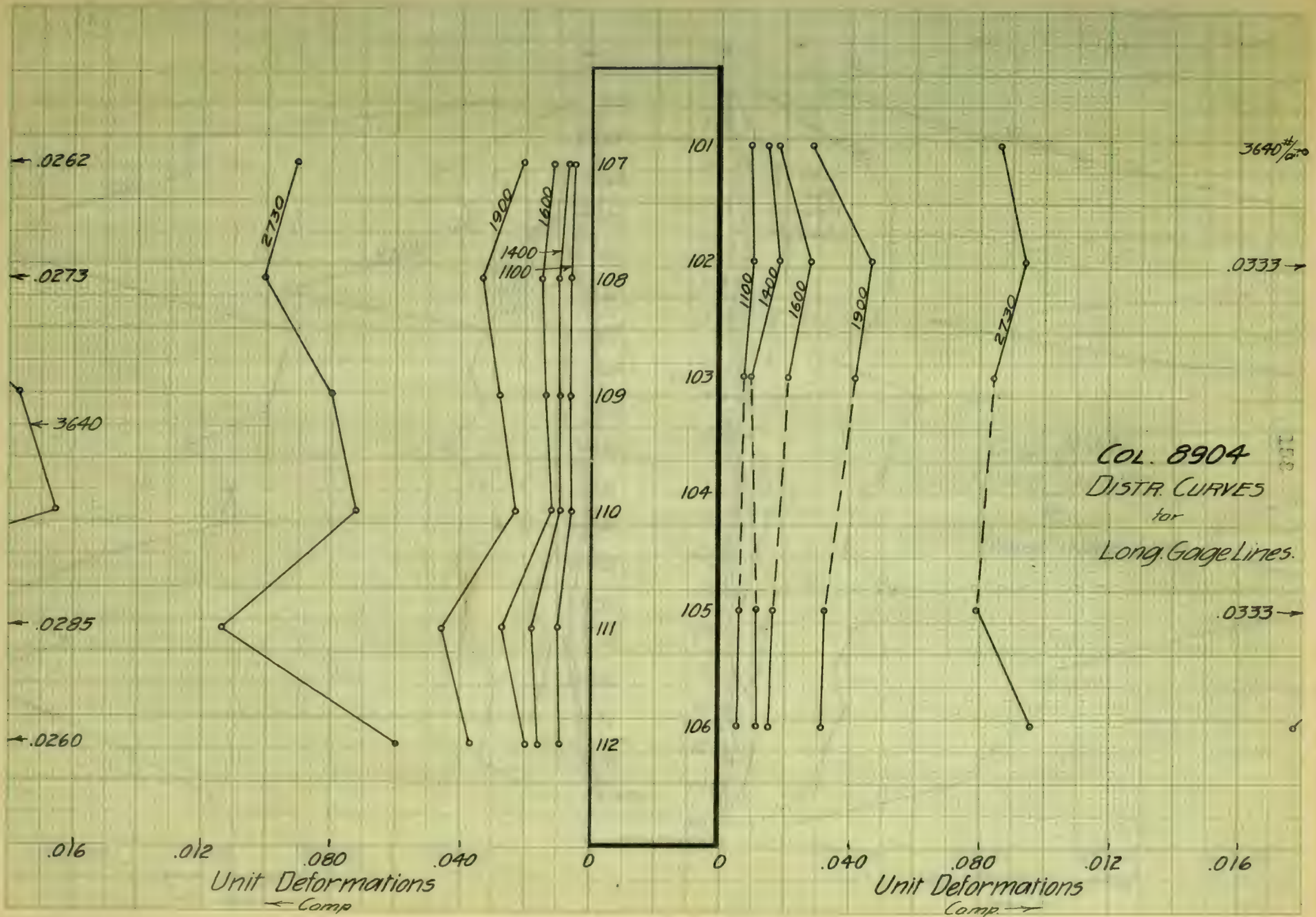
COL 8902
DISTR. CURVES
for
Long. Gage Lines.





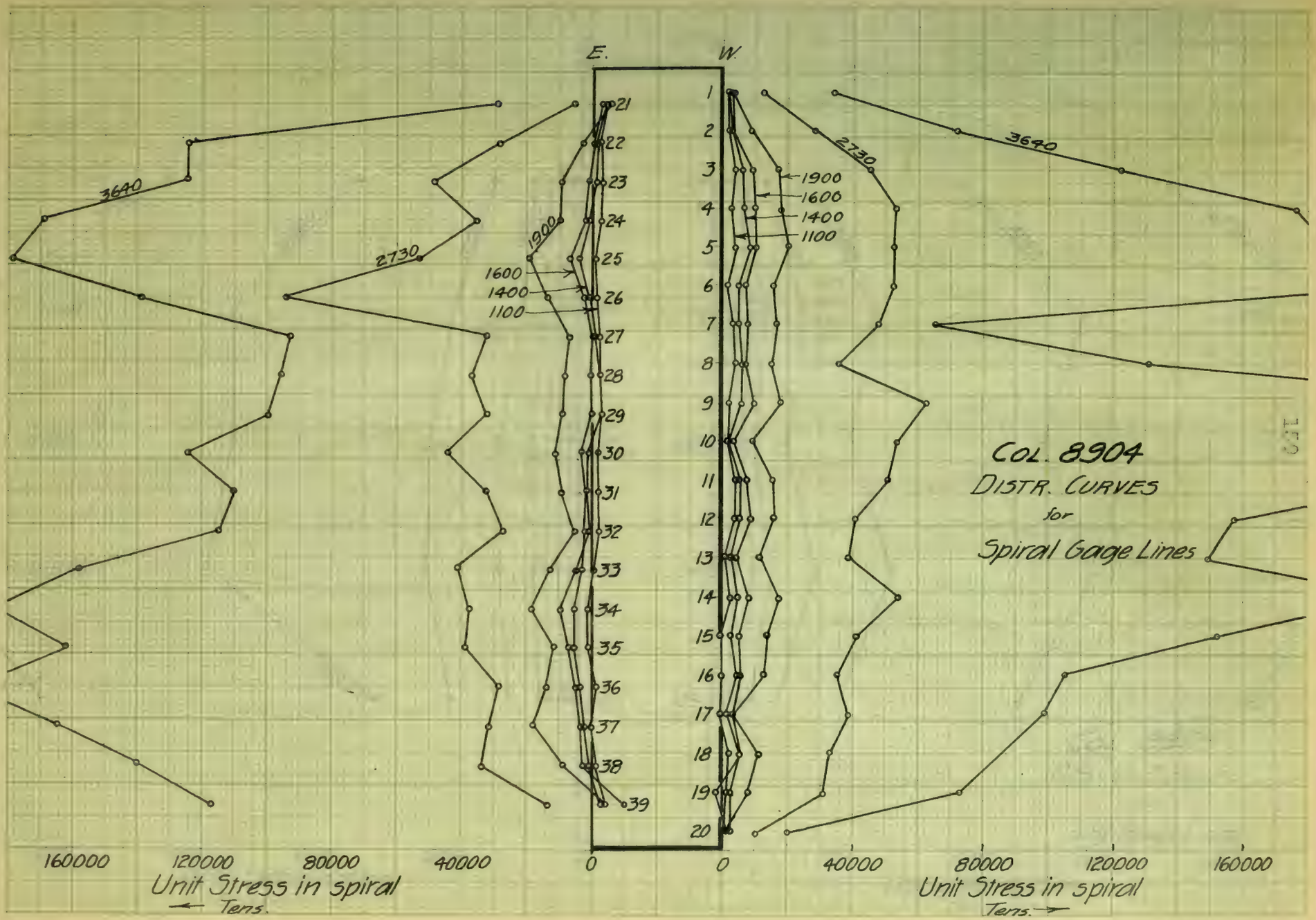
COL. 8902
DISTR. CURVES
for
Spiral Gage Lines

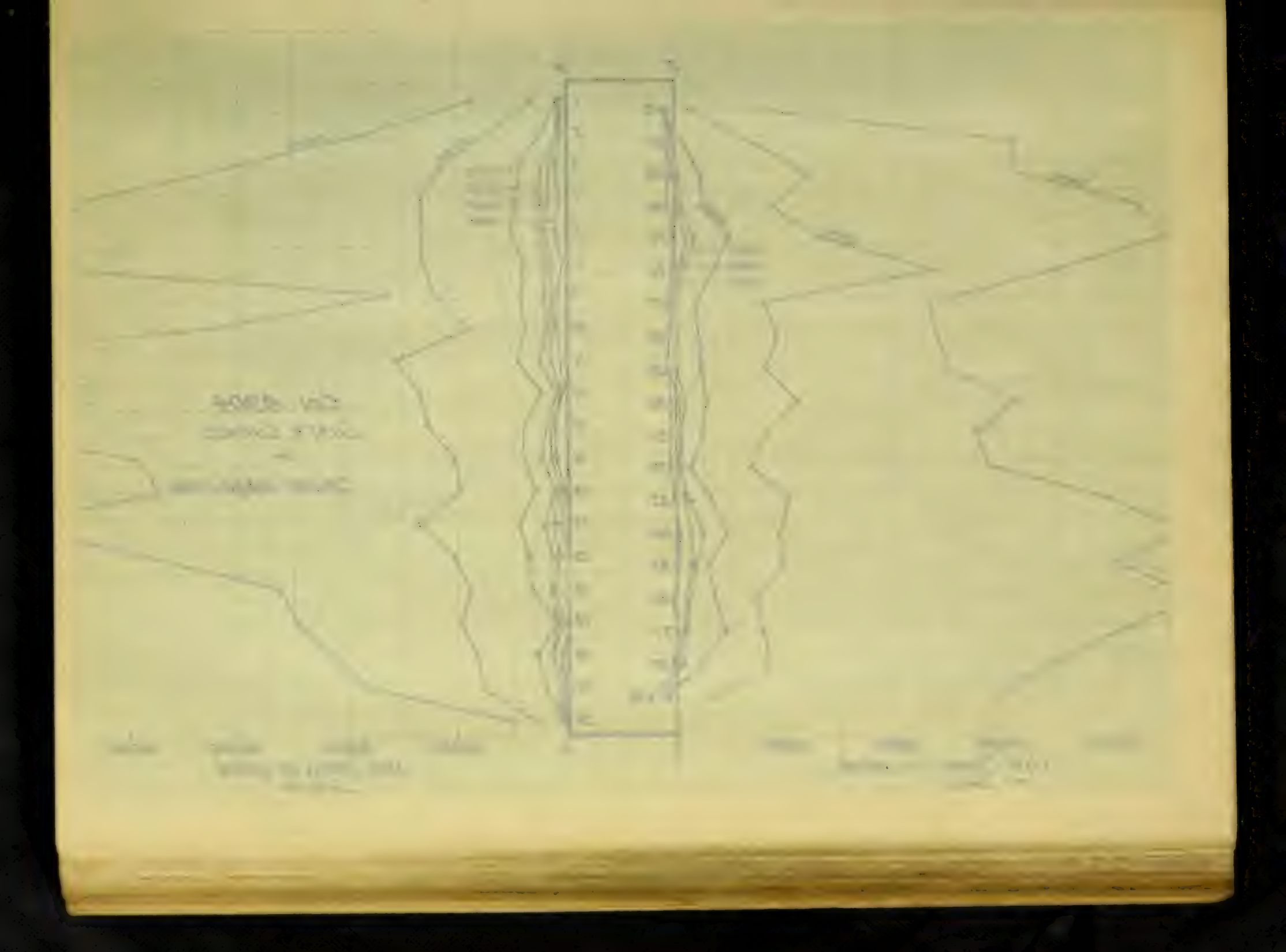


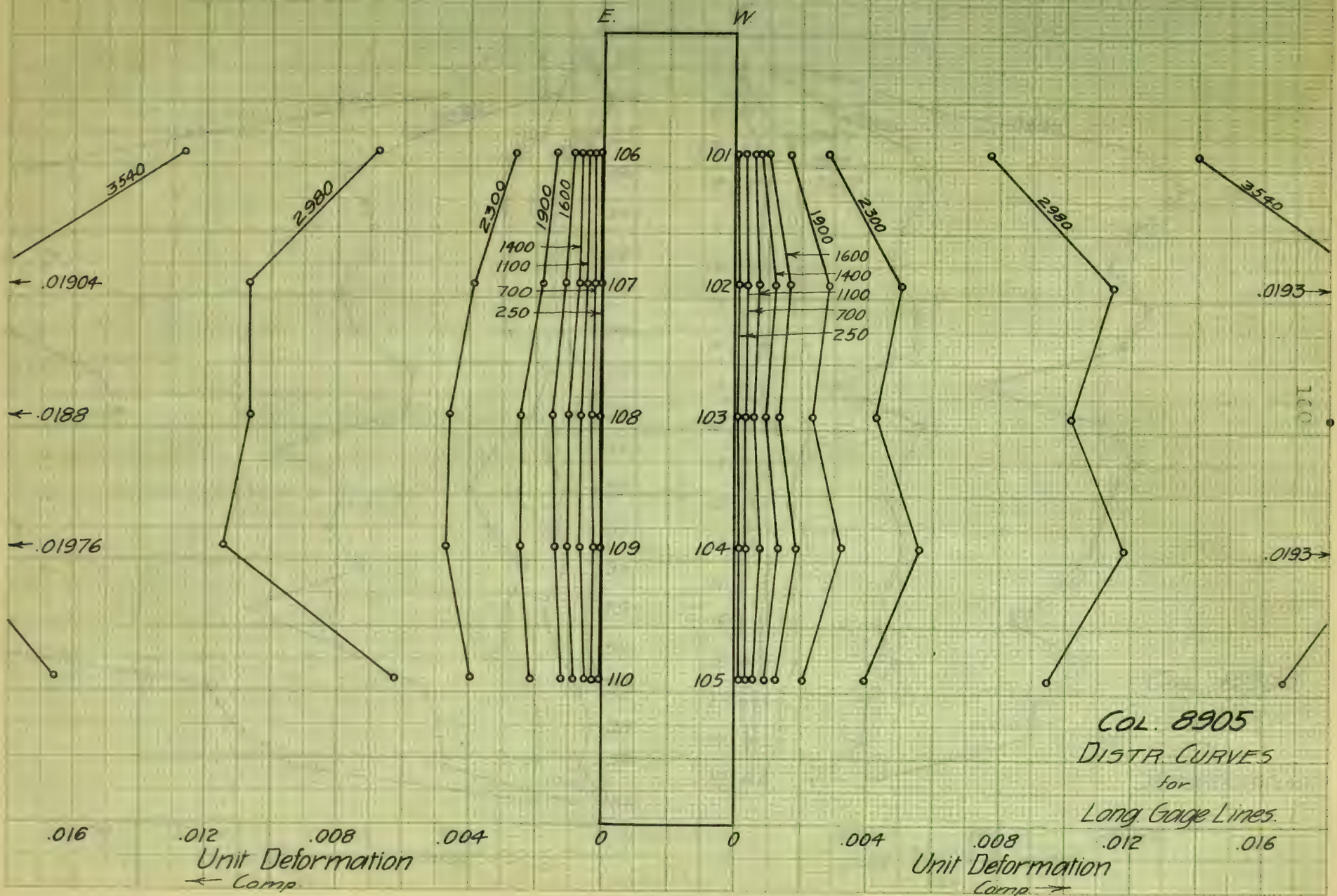


COL. 8904
DISTR. CURVES
for
Long. Gage Lines.

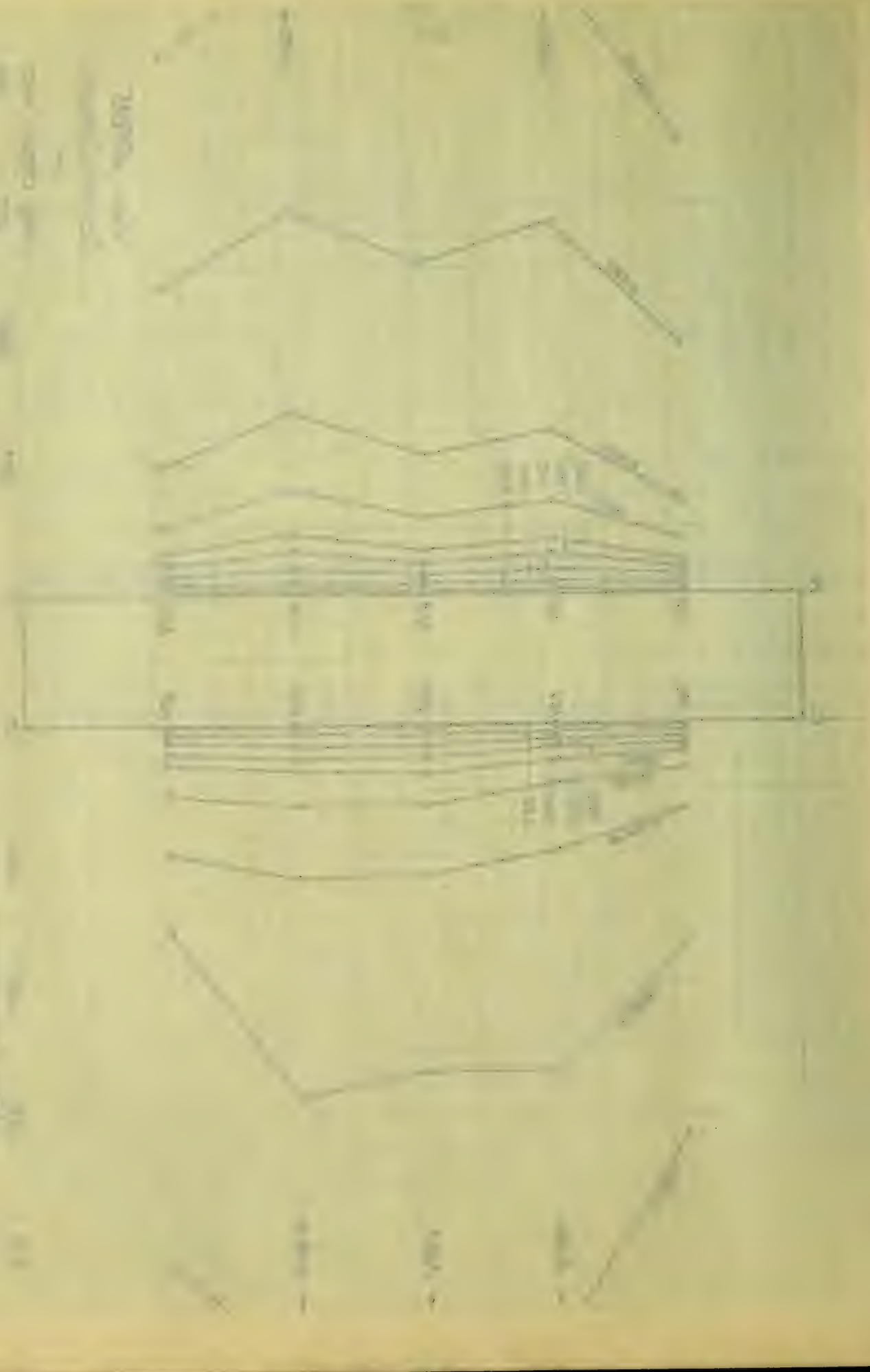


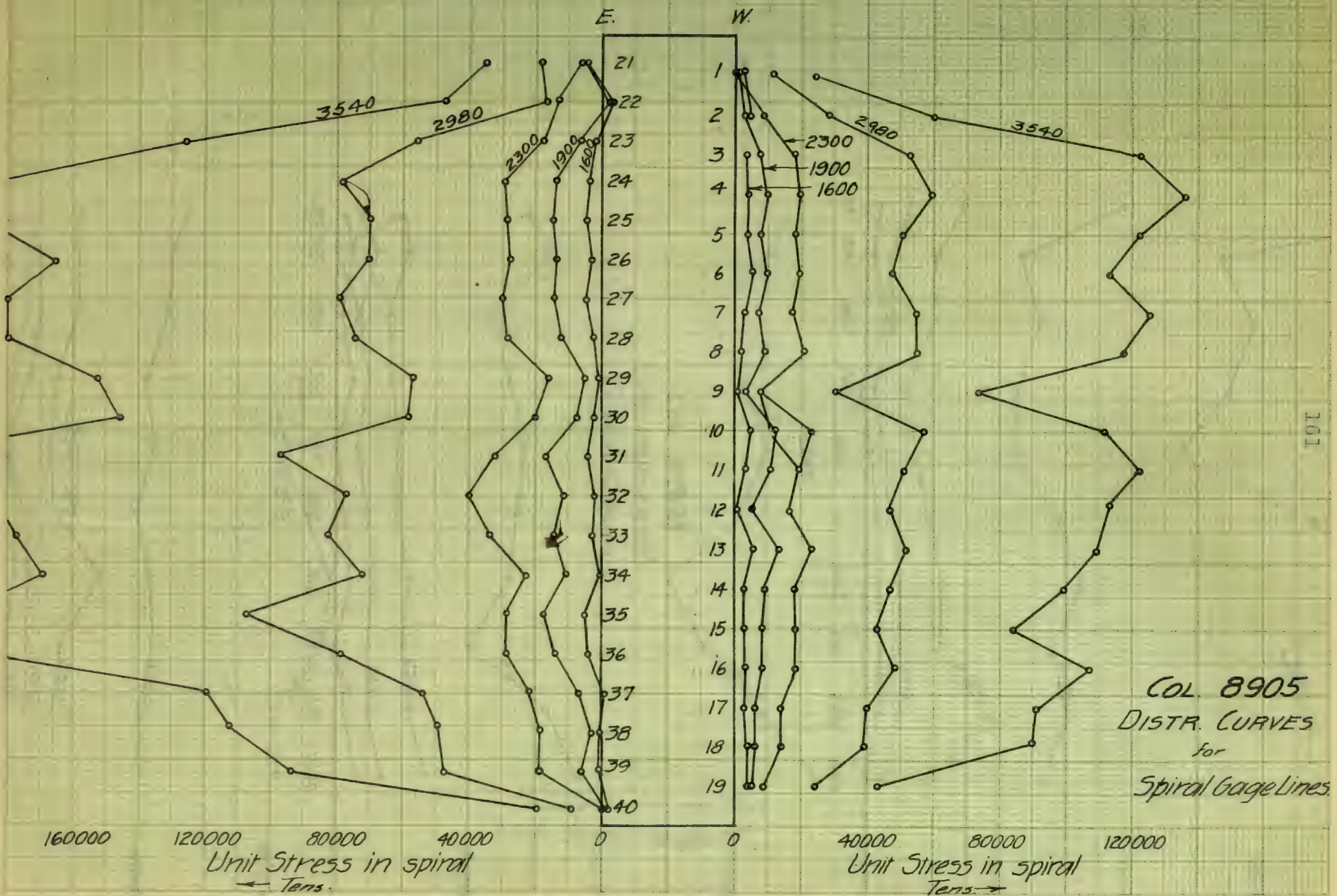

E.
W.
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
3640
2730
1900
1600
1400
1100
160000
120000
80000
40000
0
Unit Stress in spiral
← Tens.
Unit Stress in spiral
Tens. →
COL. 8904
DISTR. CURVES
for
Spiral Gage Lines



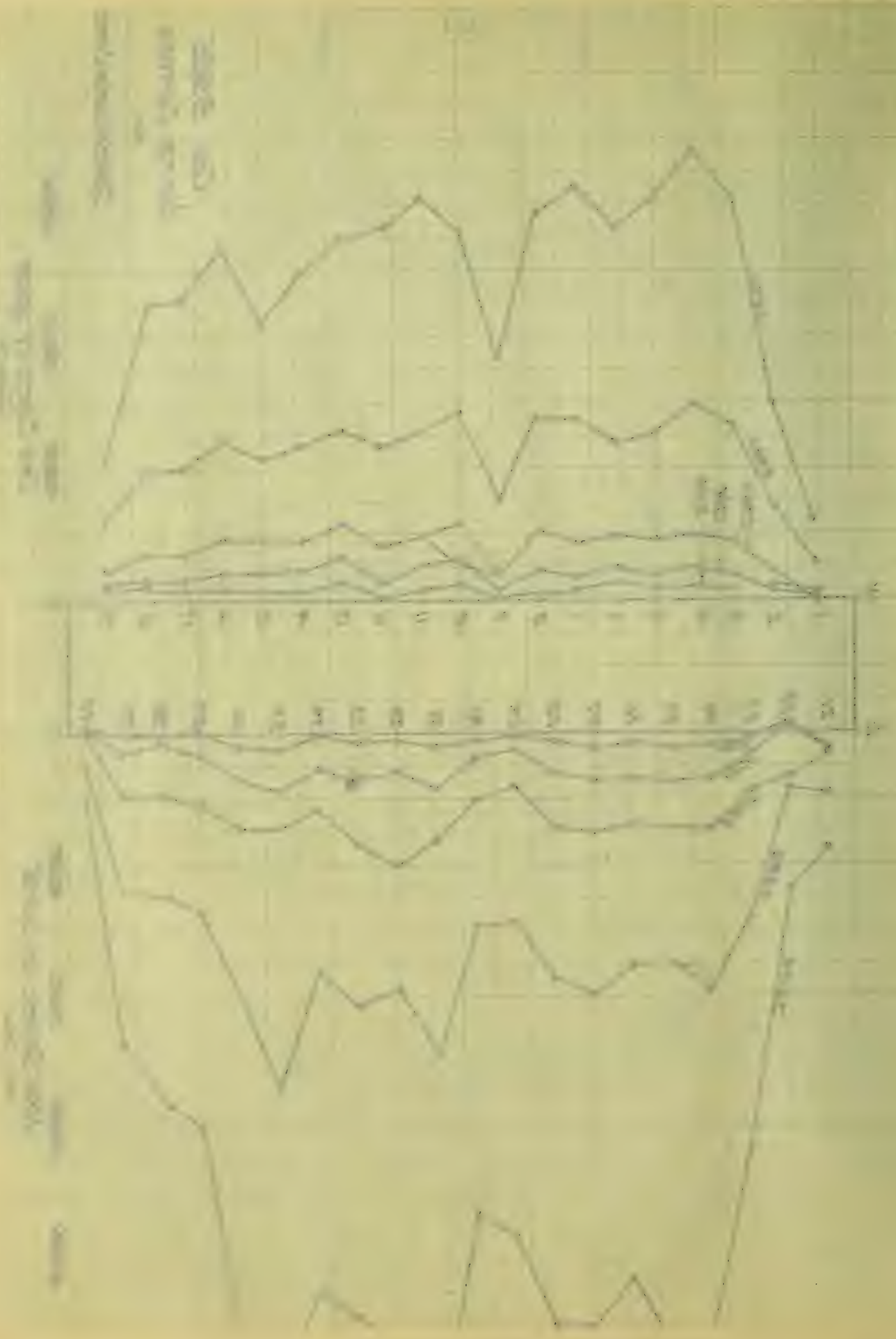


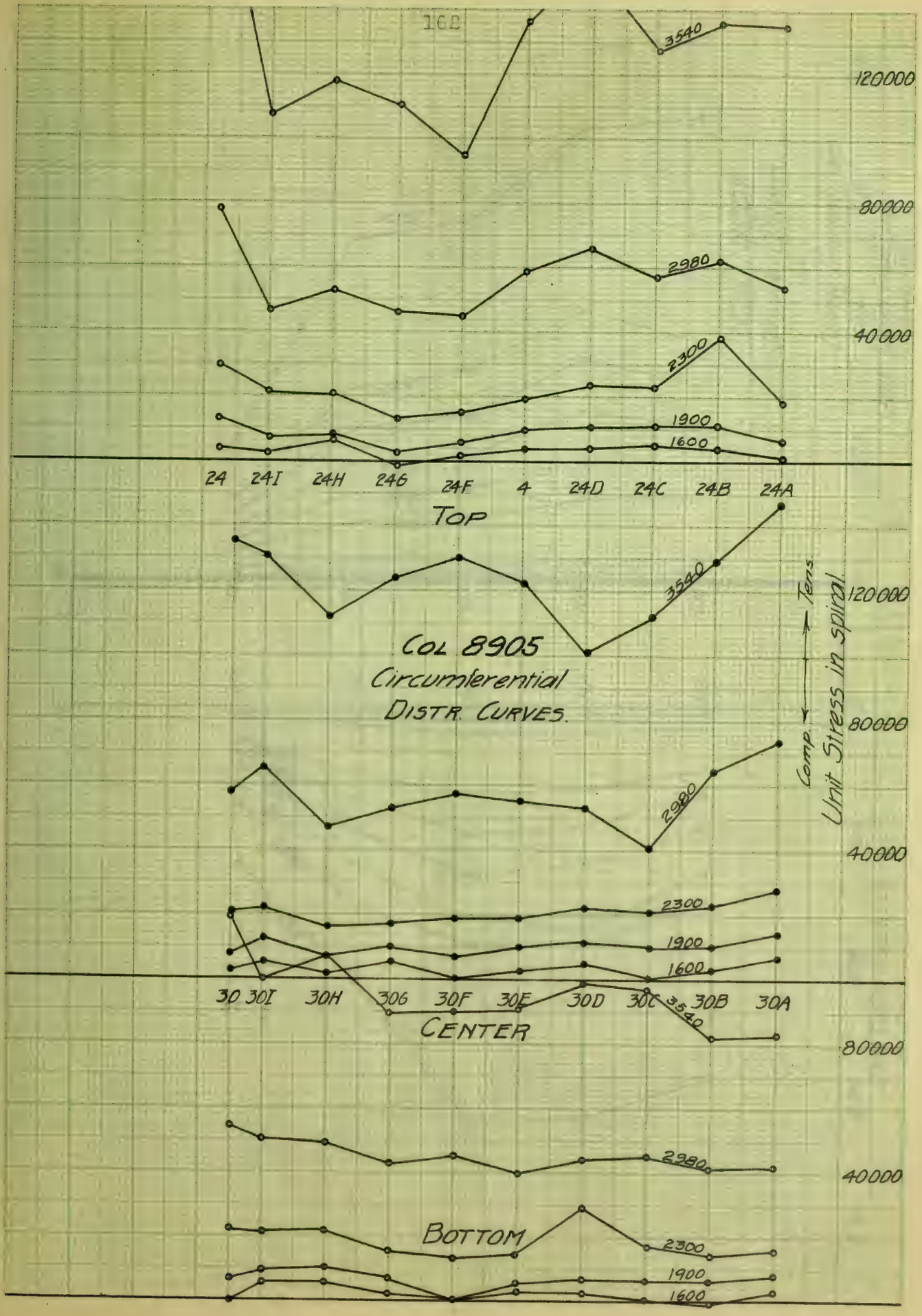
COL. 8905
DISTR. CURVES
for
Long. Gage Lines.

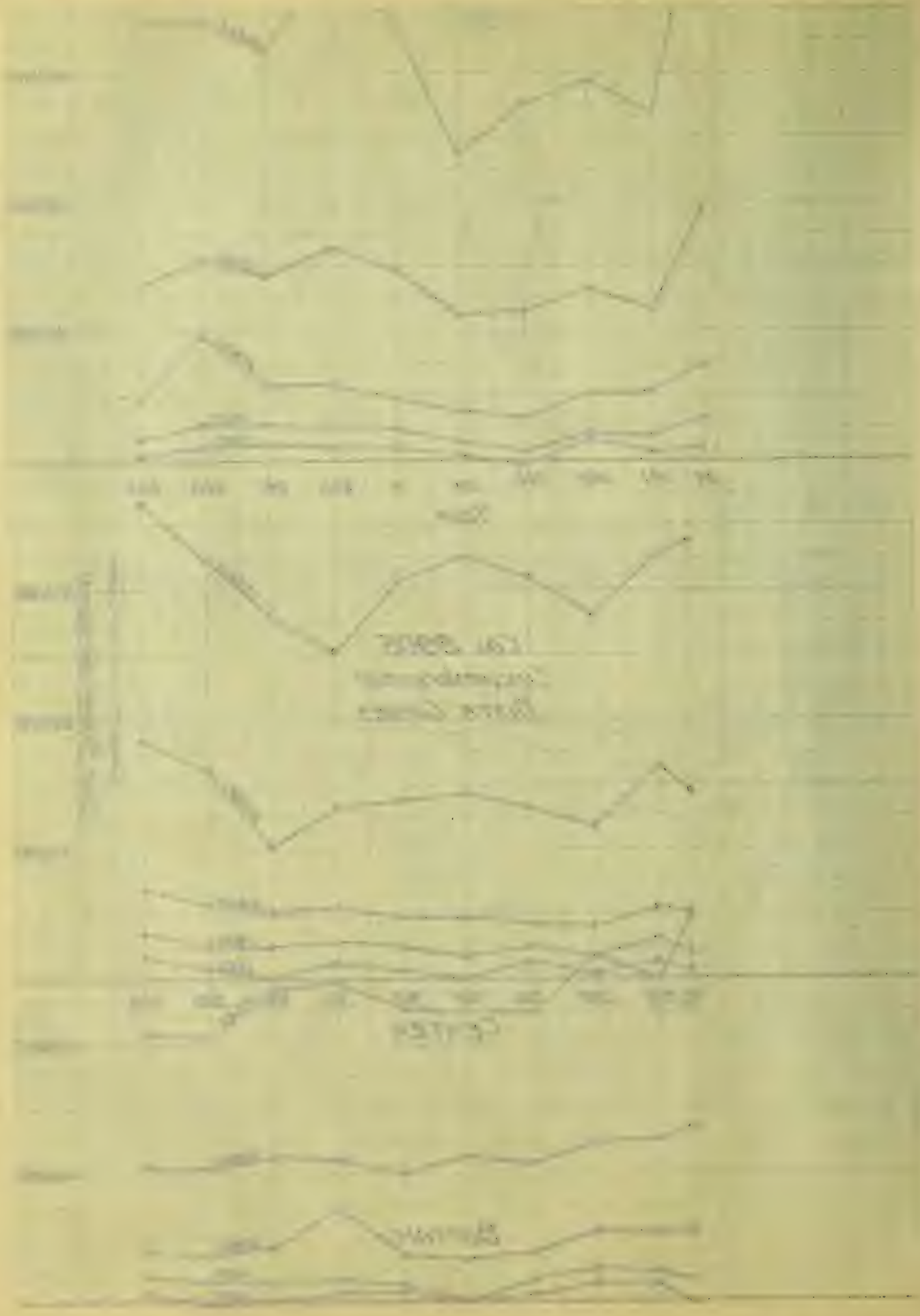


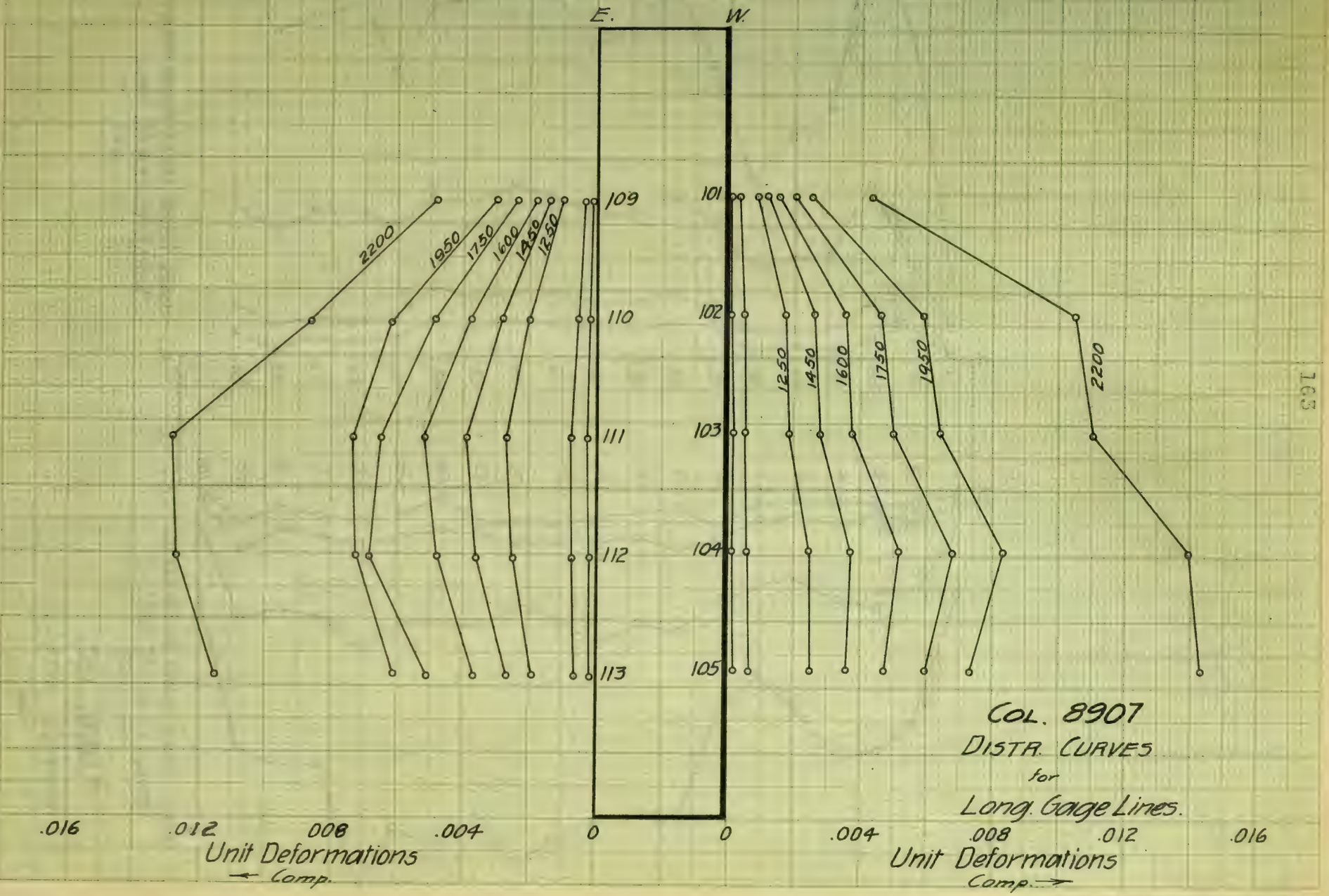


COL. 8905
DISTR. CURVES
for
Spiral Gage Lines.



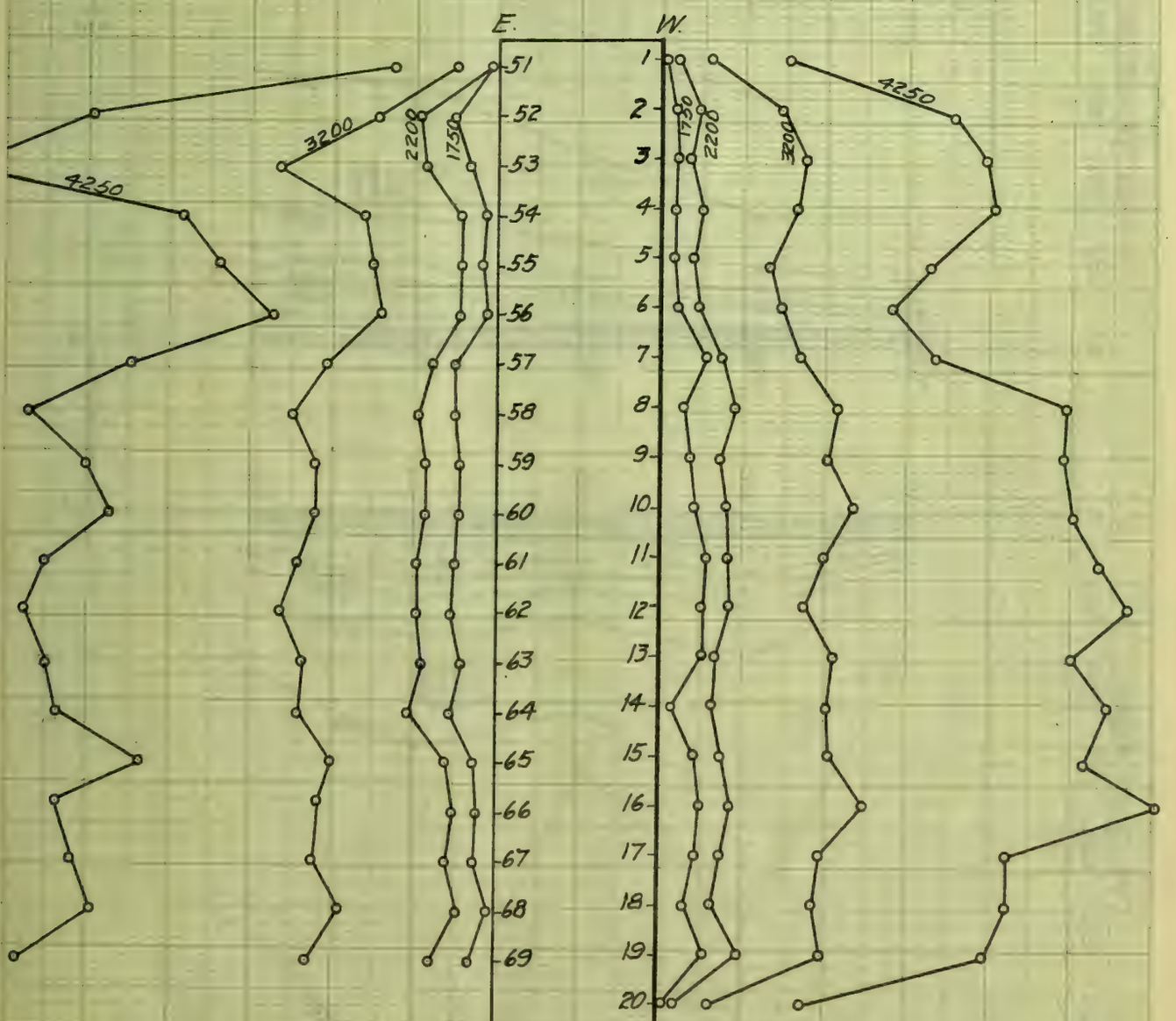

3540
120000
80000
2980
40000
2300
1900
1600
24 24I 24H 24G 24F 4 24D 24C 24B 24A
TOP
3540
120000
COL 8905
CIRCUMFERENTIAL
DISTR. CURVES.
Comp. ← → Tens.
Unit Stress in spiral
80000
2980
40000
2300
1900
1600
30 30I 30H 30G 30F 30E 30D 30C 30B 30A
3540
CENTER
80000
2980
40000
BOTTOM
2300
1900
1600





COL. 8907
DISTR. CURVES
for
Long. Gage Lines.





100000 80000 60000 40000 20000 0

Unit Stress in spiral

← Tons.

0 20000 40000 60000 80000 100000

Unit Stress in spiral

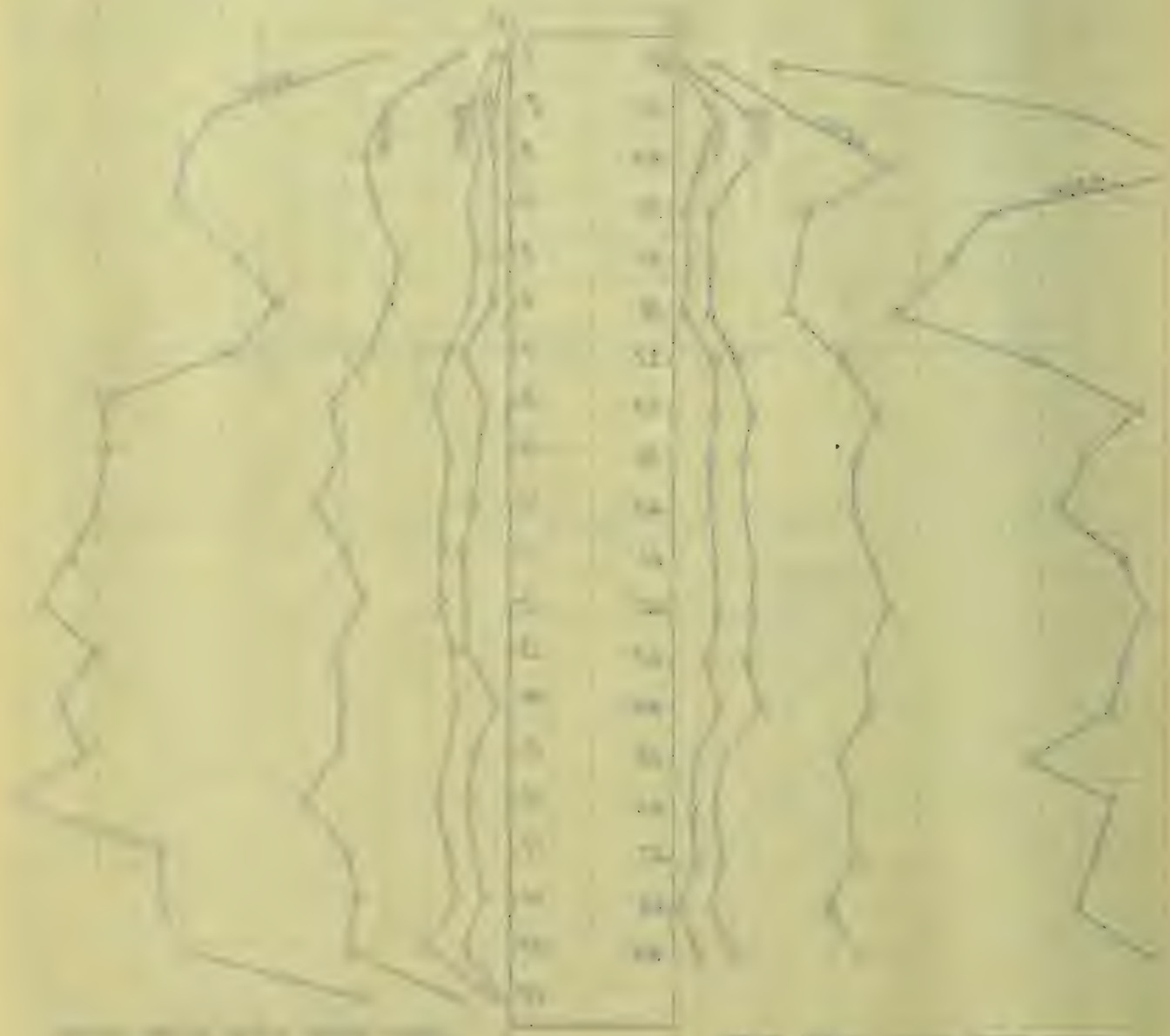
Tons. →

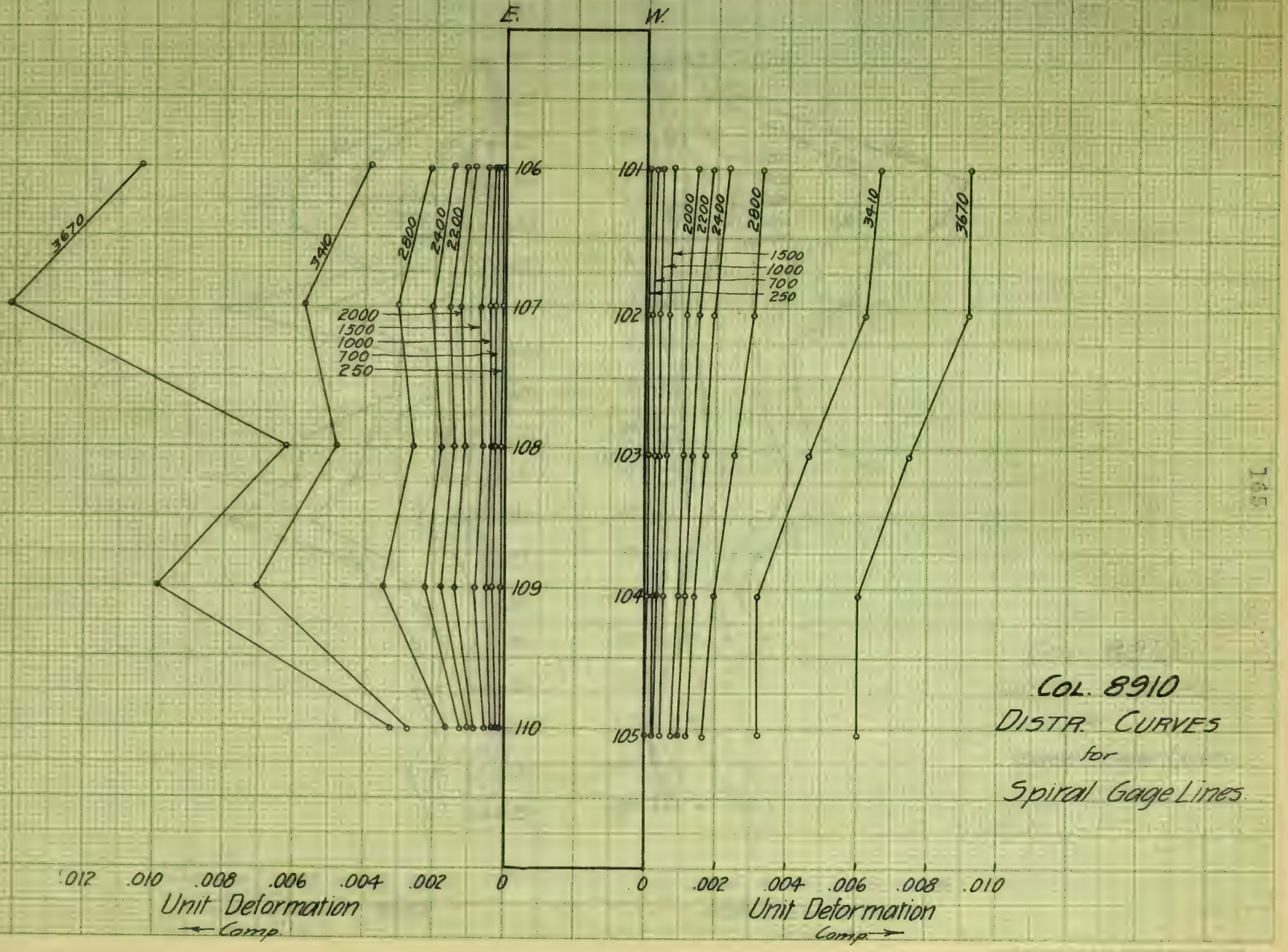
COL. 8907

DISTR. CURVES

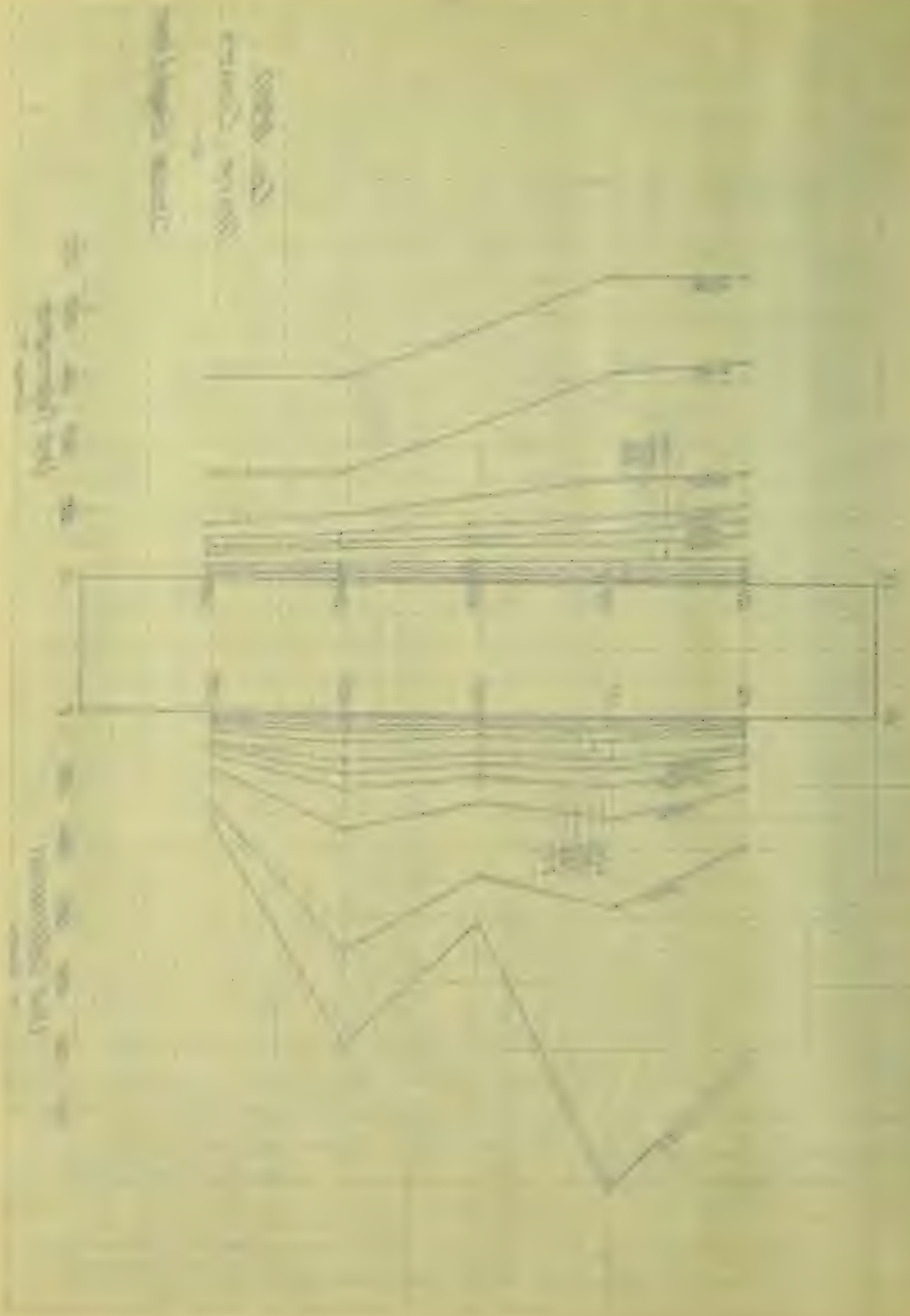
for

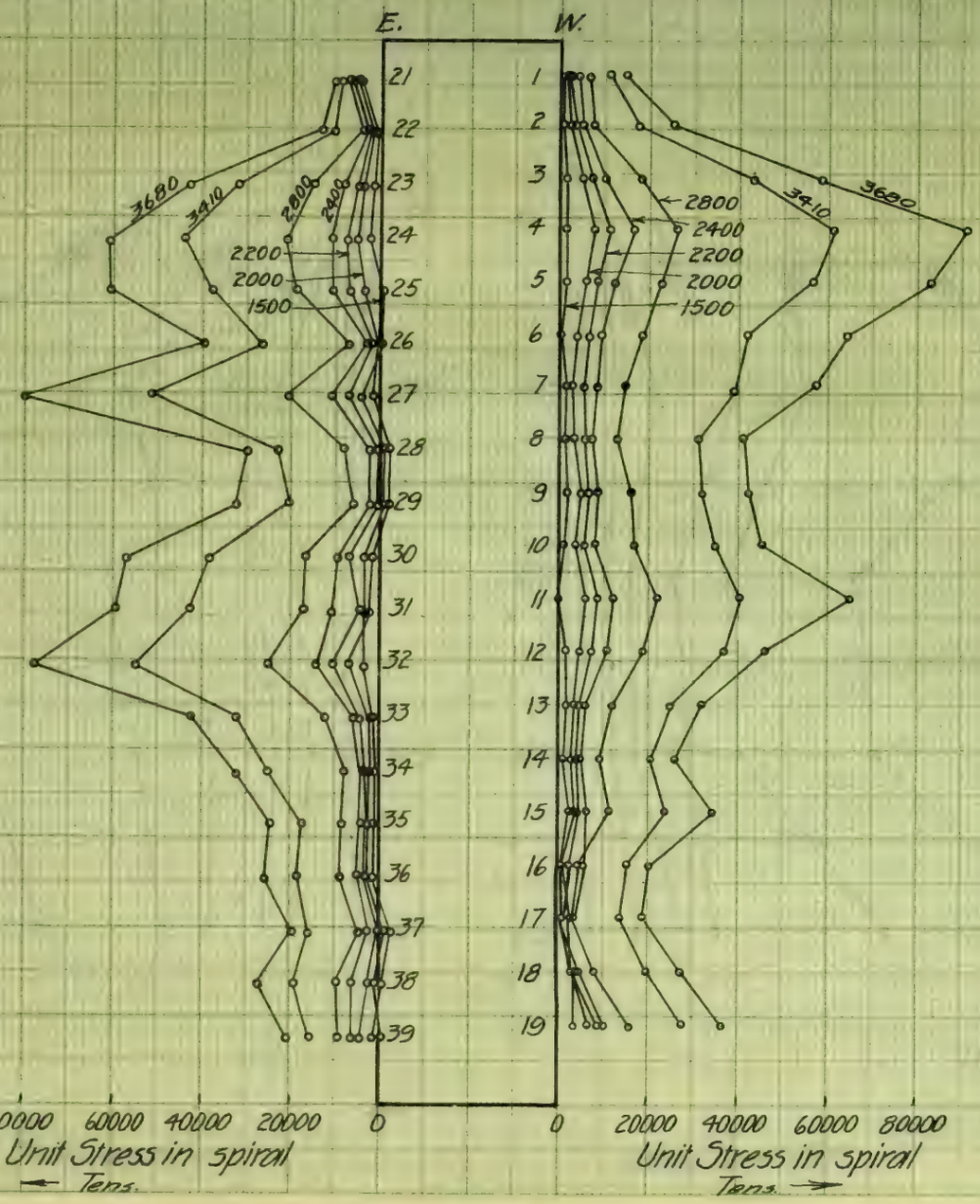
Spiral Gage Lines.





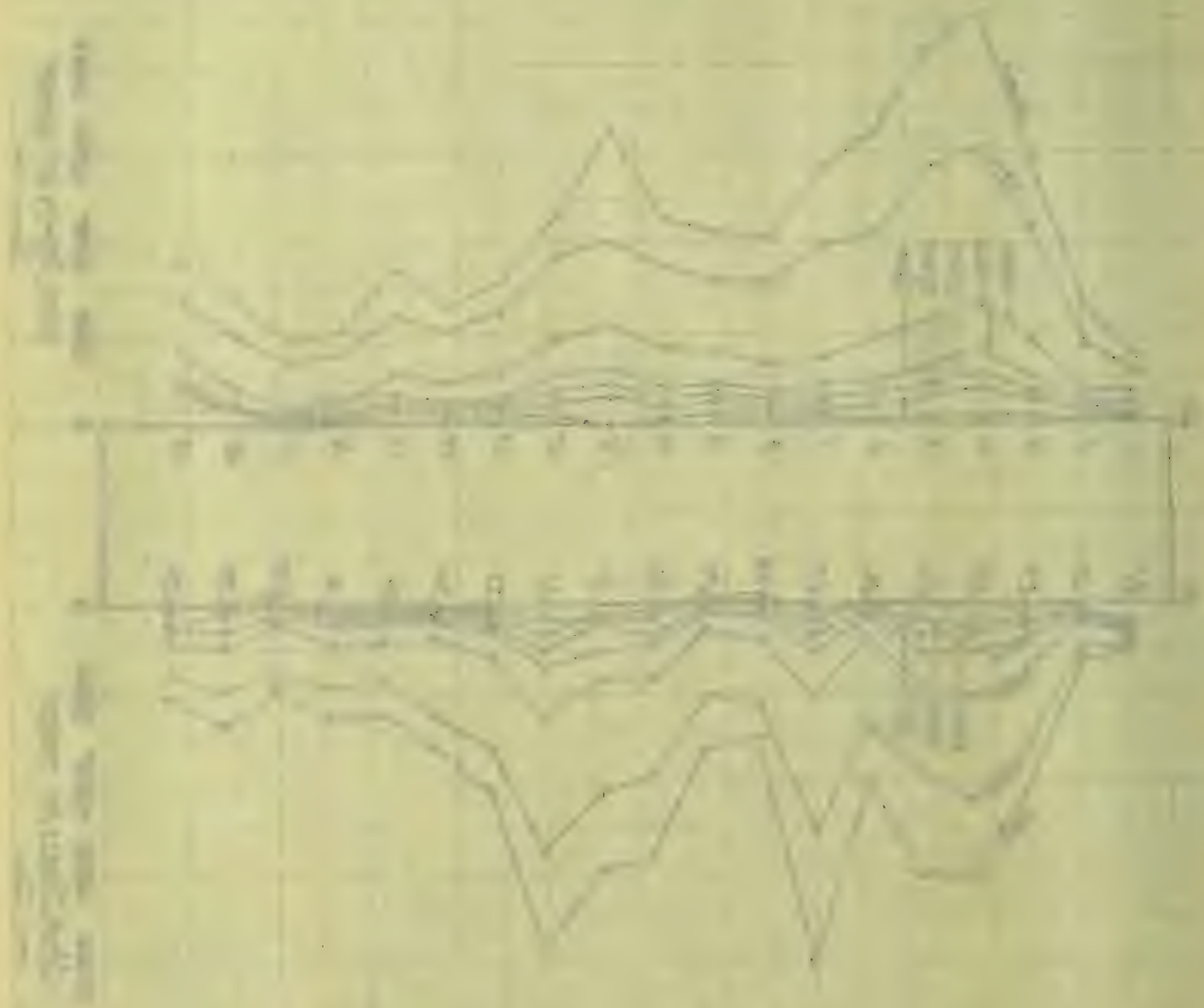
COL. 8910
DISTR. CURVES
for
Spiral Gage Lines.

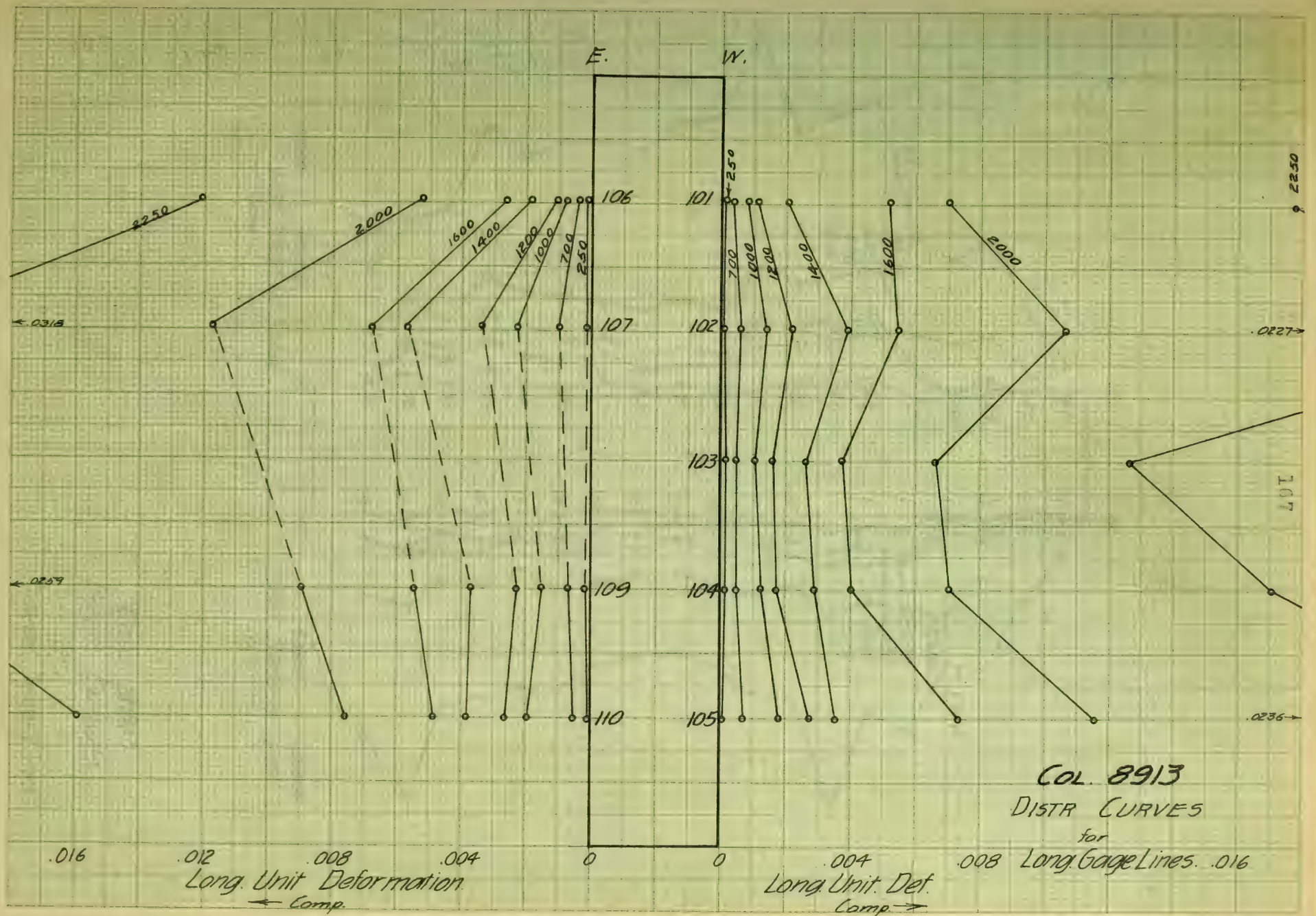


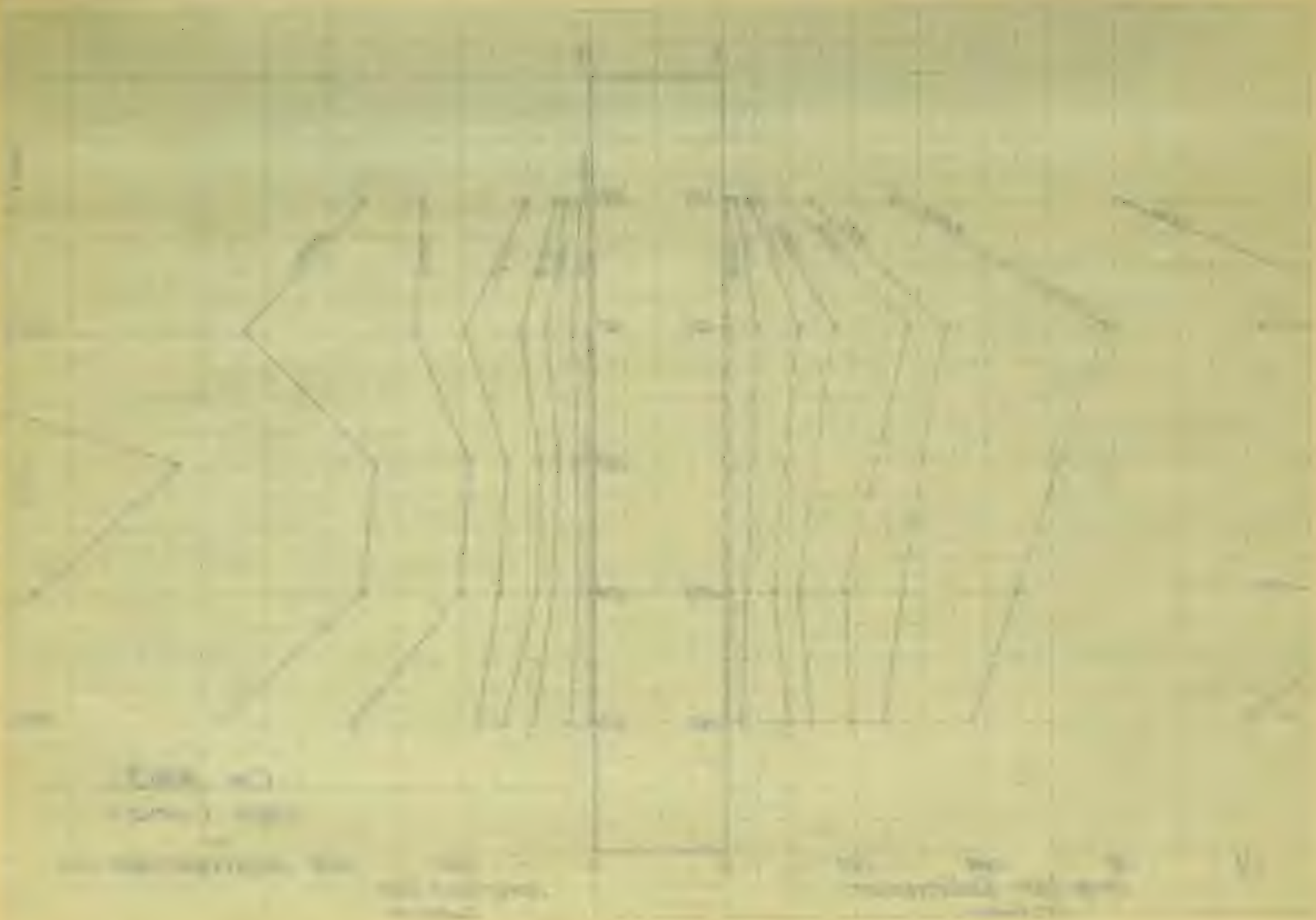


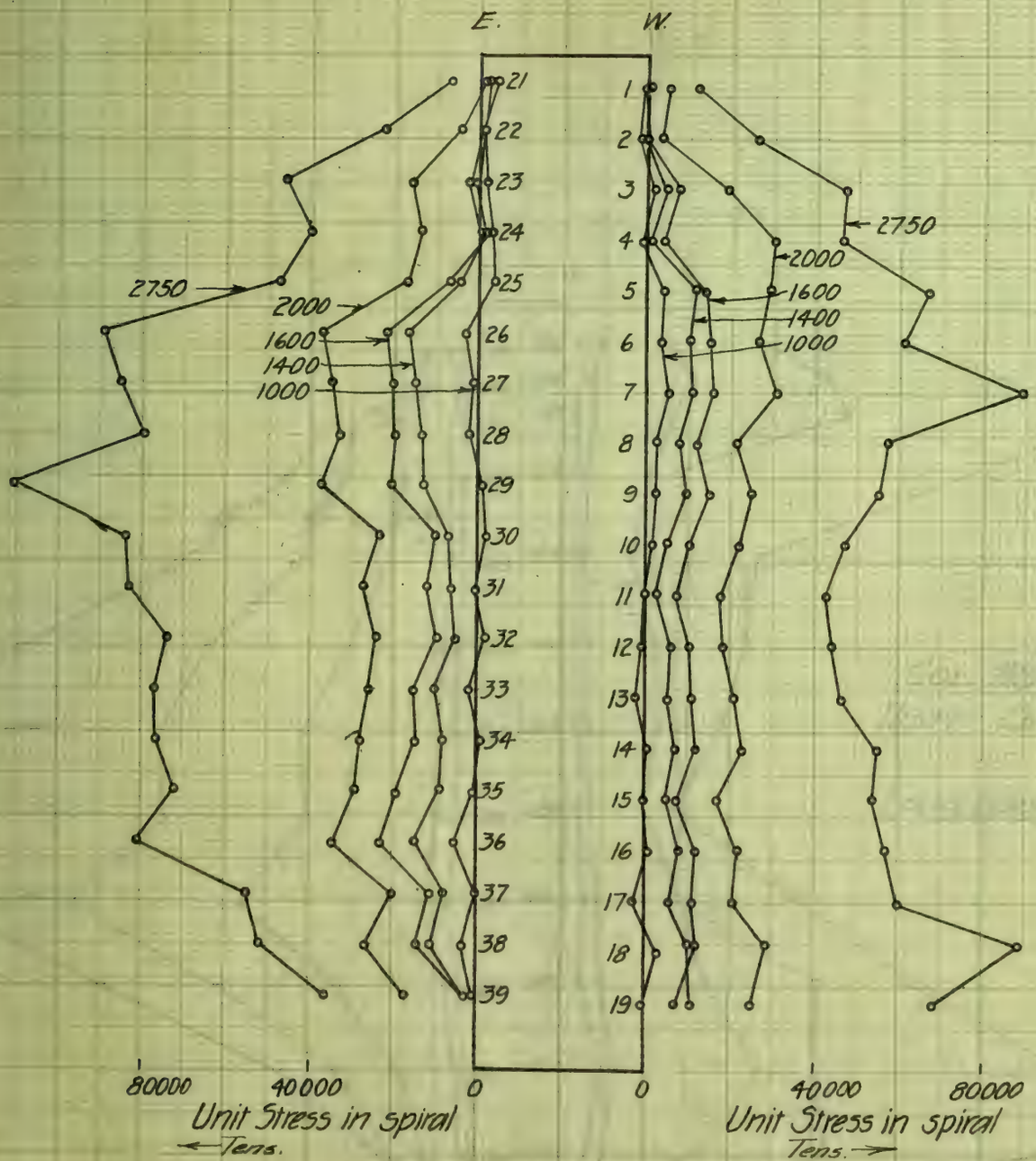
COL. 8910
DISTR. CURVES
for
Spiral Gage Lines.

166



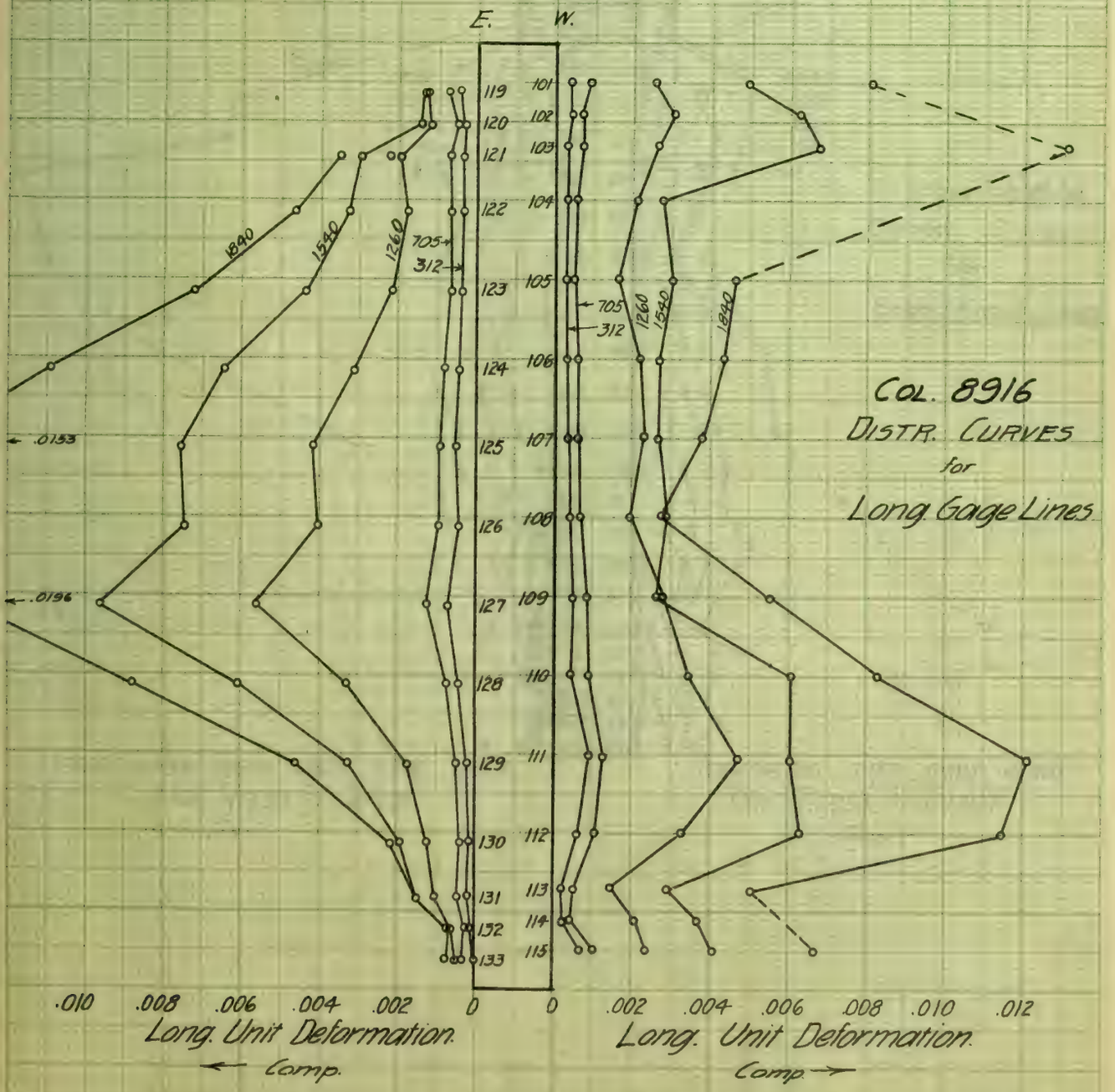

E.
W.
106
107
109
110
101
102
103
104
105
2250
2000
1600
1400
1200
1000
700
250
.0318
.0259
.0227
.0236
.016
.012
.008
.004
0
Long. Unit Deformation
← Comp.
Long. Unit. Def.
Comp. →
COL. 8913
DISTR CURVES
for
Long. Gage Lines.





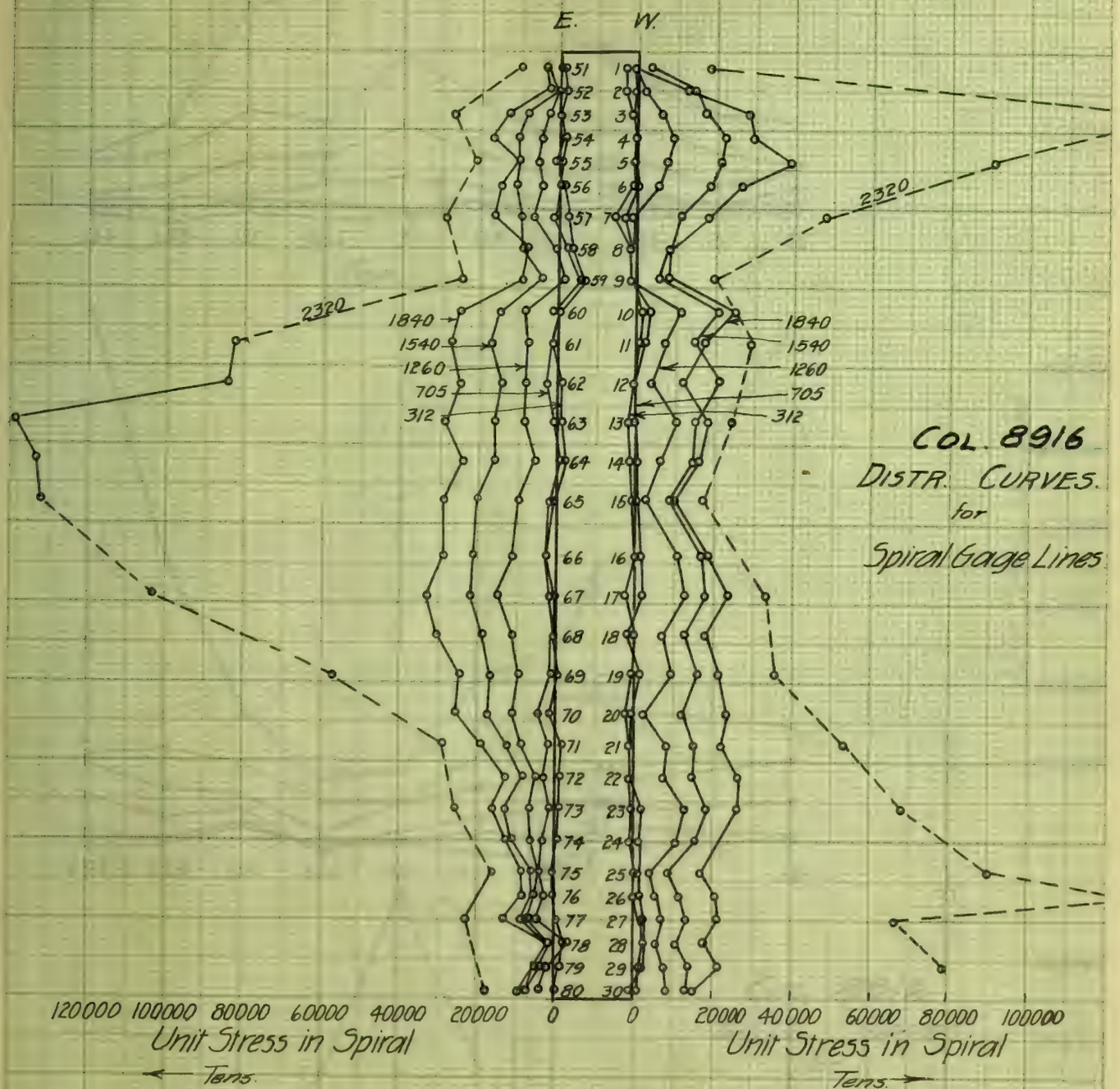
COL. 8913
DISTR. CURVES
for
Spiral Gage Lines.





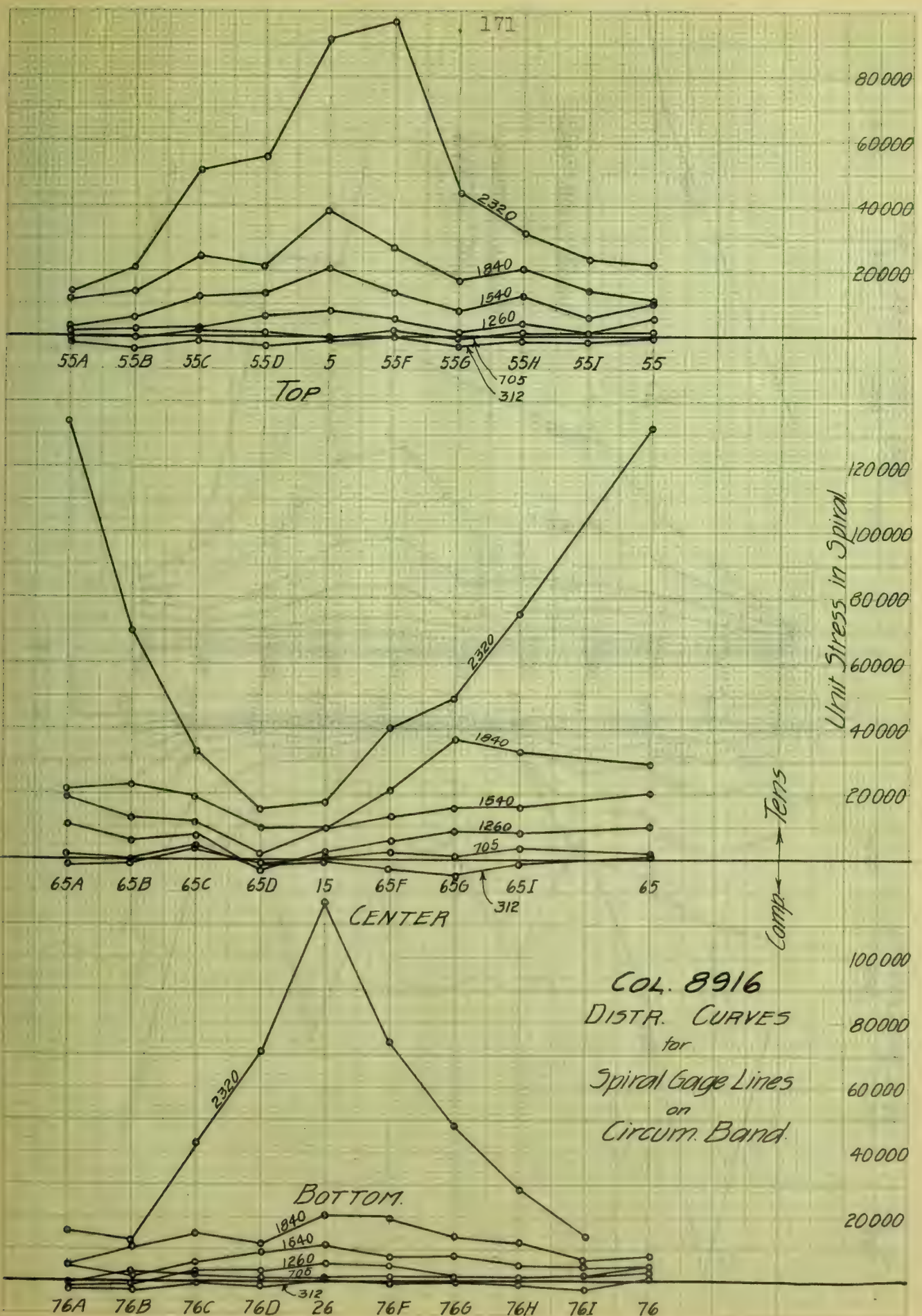
COL. 8916
DISTR. CURVES
for
Long. Gage Lines.



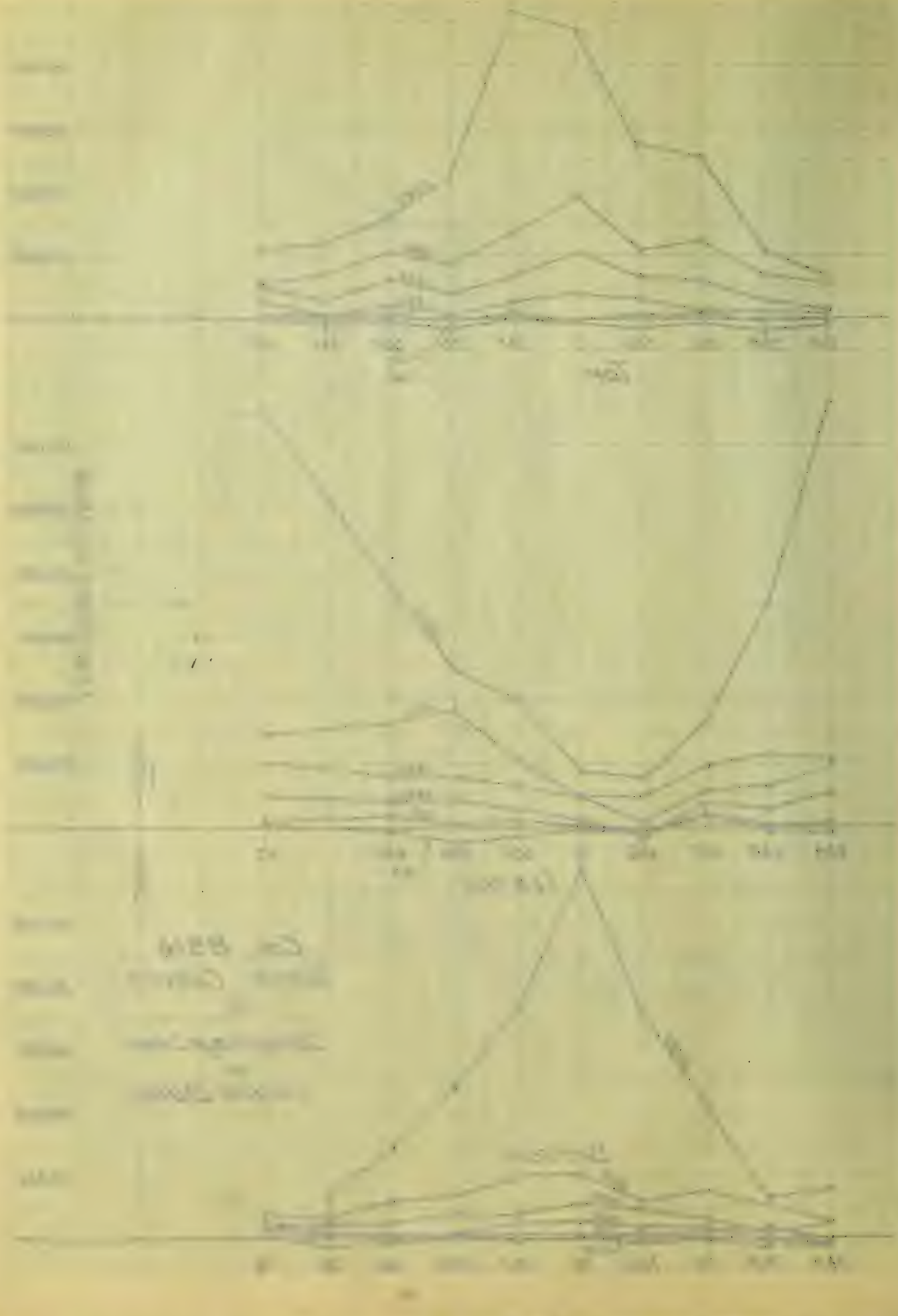


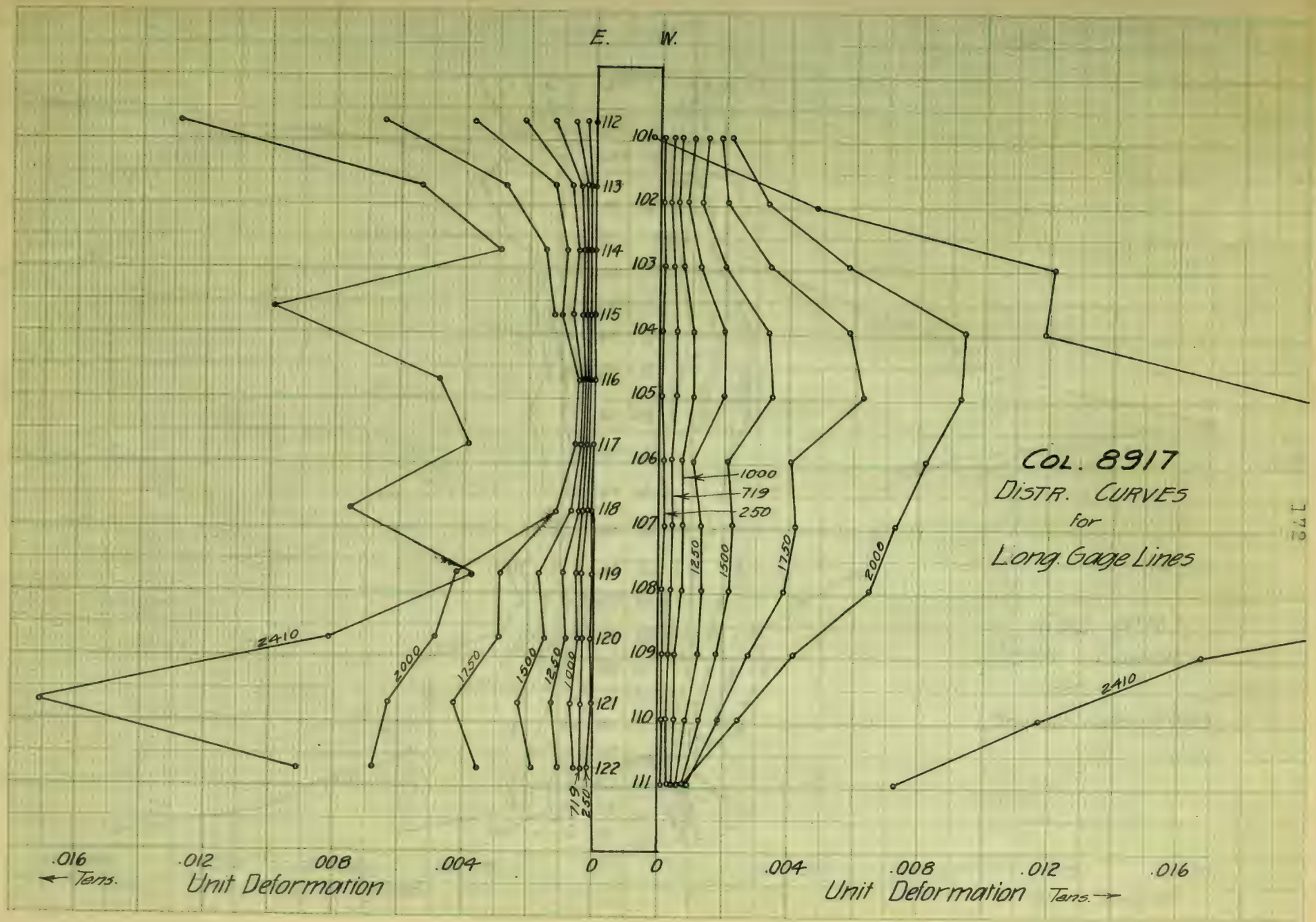
COL. 8916
DISTR. CURVES.
for
Spiral Gage Lines



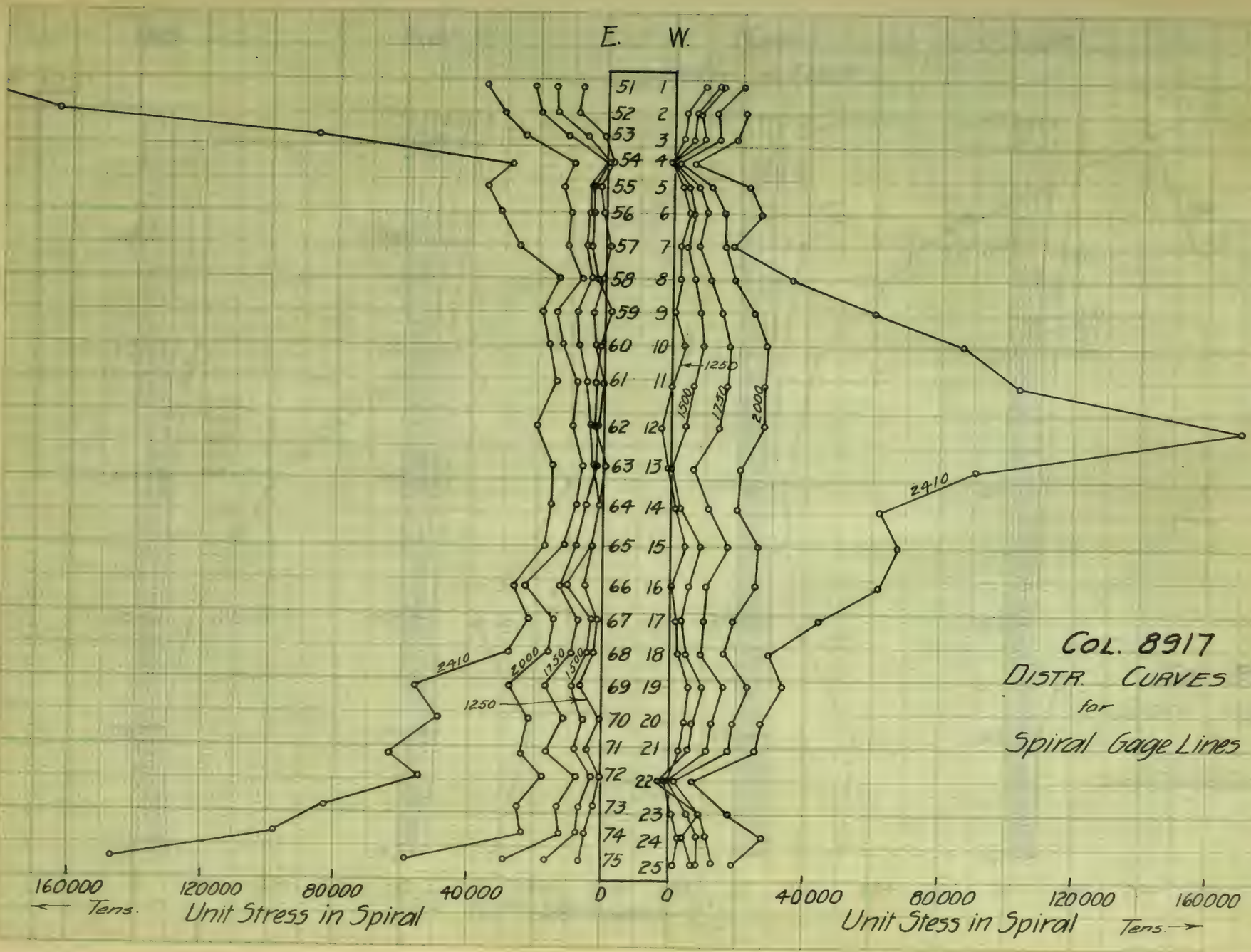


COL. 8916
DISTR. CURVES
for
Spiral Gage Lines
on
Circum. Band.



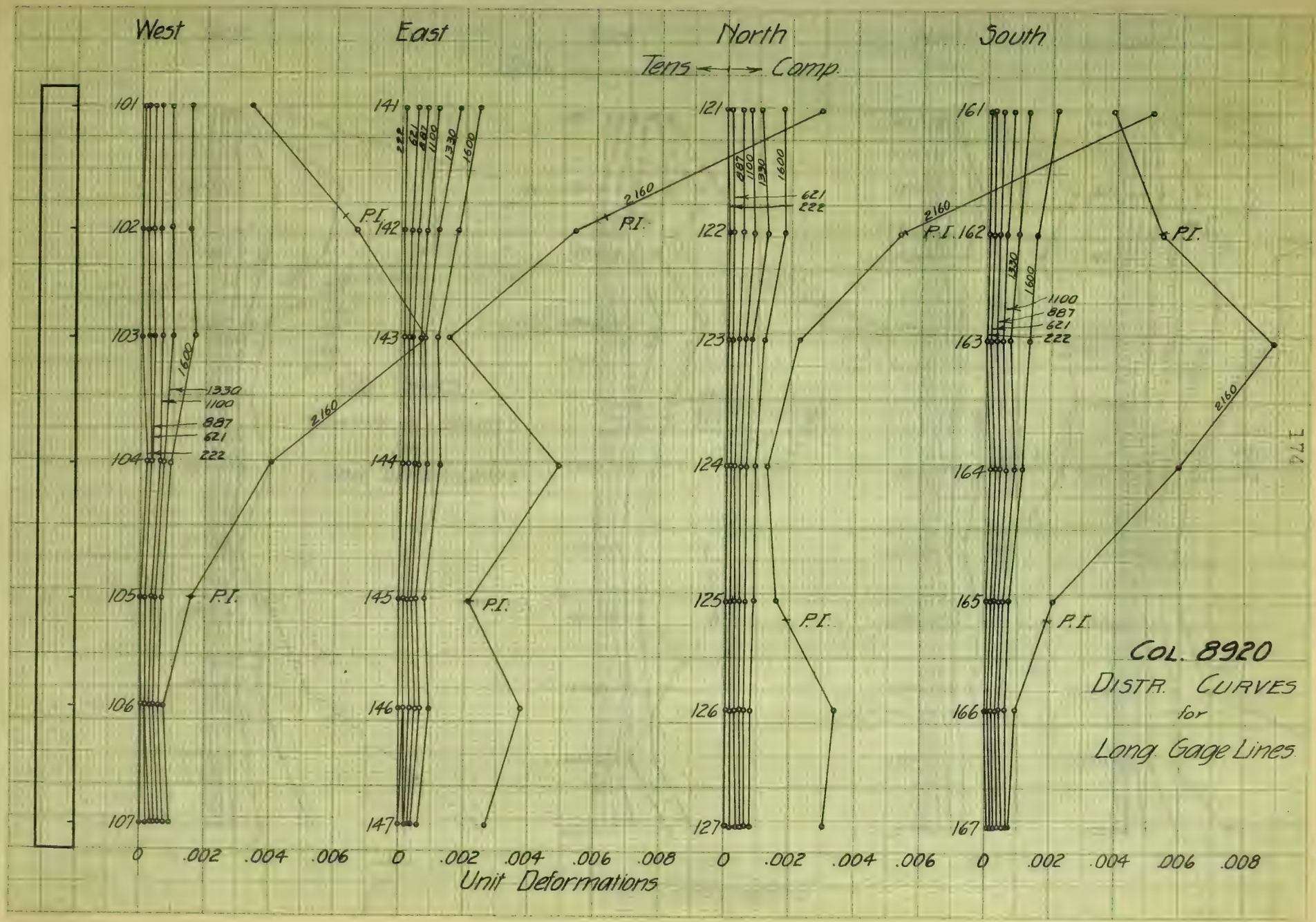

E.
W.
112
113
114
115
116
117
118
119
120
121
122
101
102
103
104
105
106
107
108
109
110
111
1000
719
250
1250
1500
1750
2000
2410
719
250
.016
← Tens.
.012
.008
.004
0
0
.004
.008
.012
.016
Unit Deformation
Unit Deformation Tens. →
COL. 8917
DISTR. CURVES
for
Long. Gage Lines
172

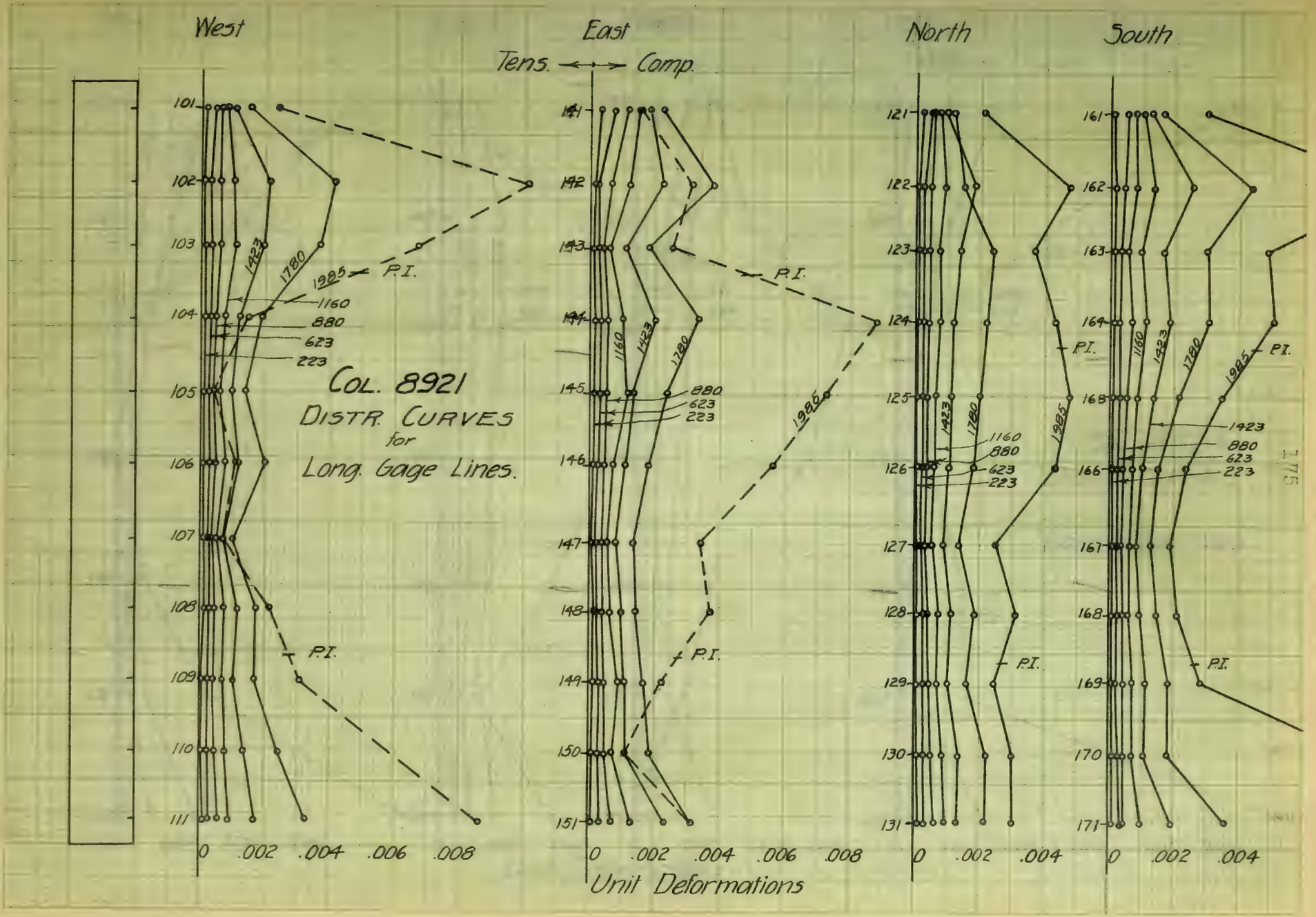


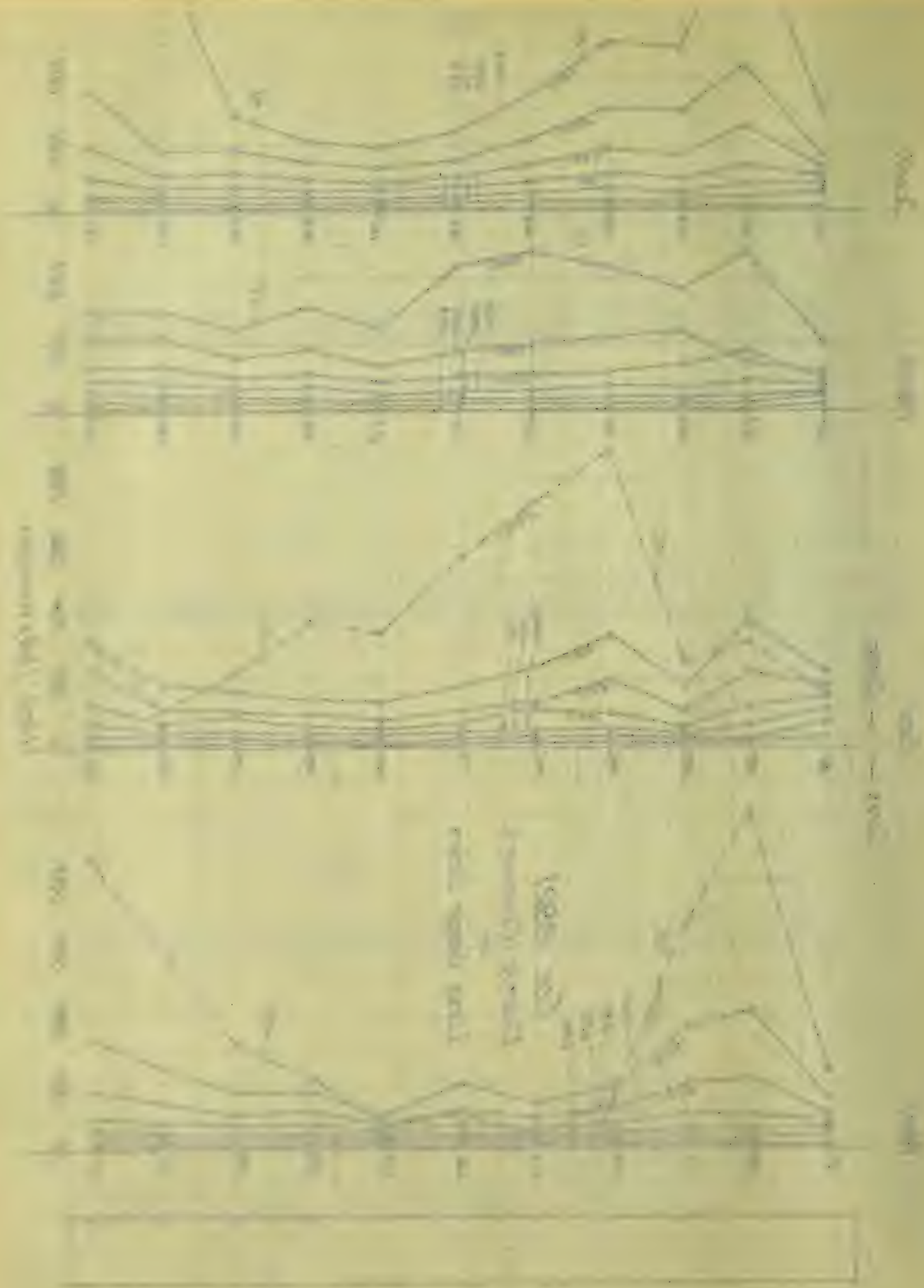


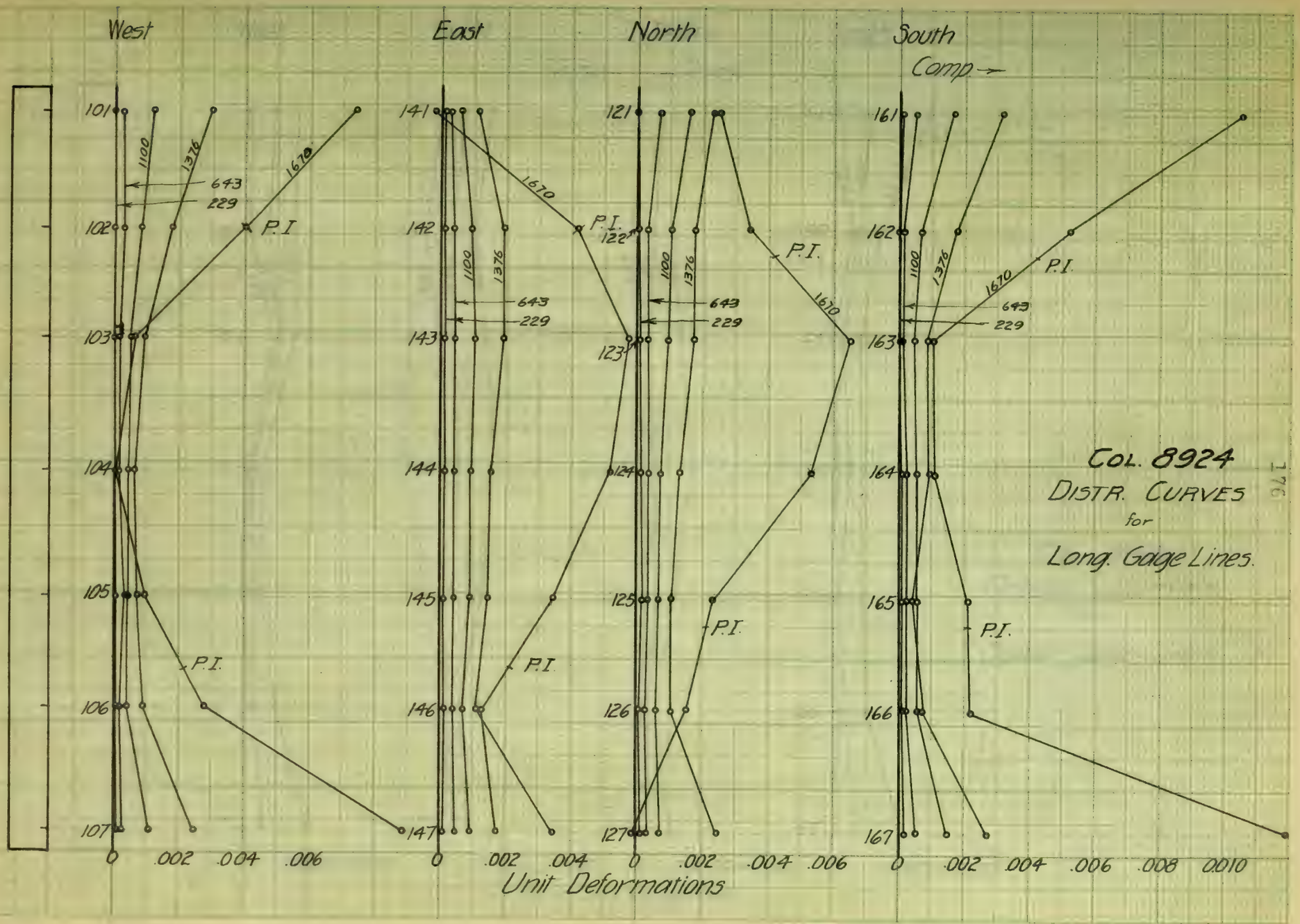
COL. 8917
DISTR. CURVES
for
Spiral Gage Lines

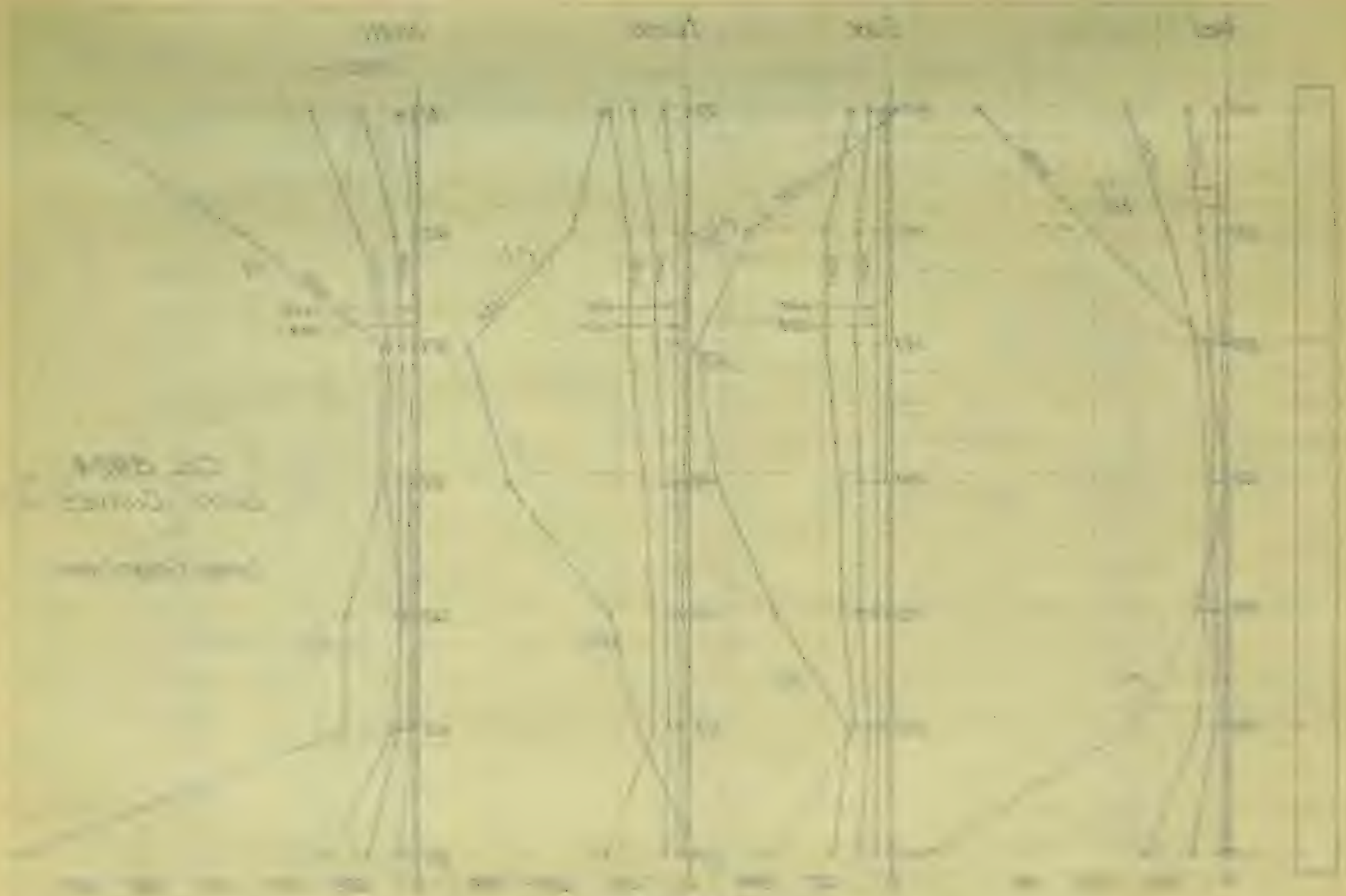


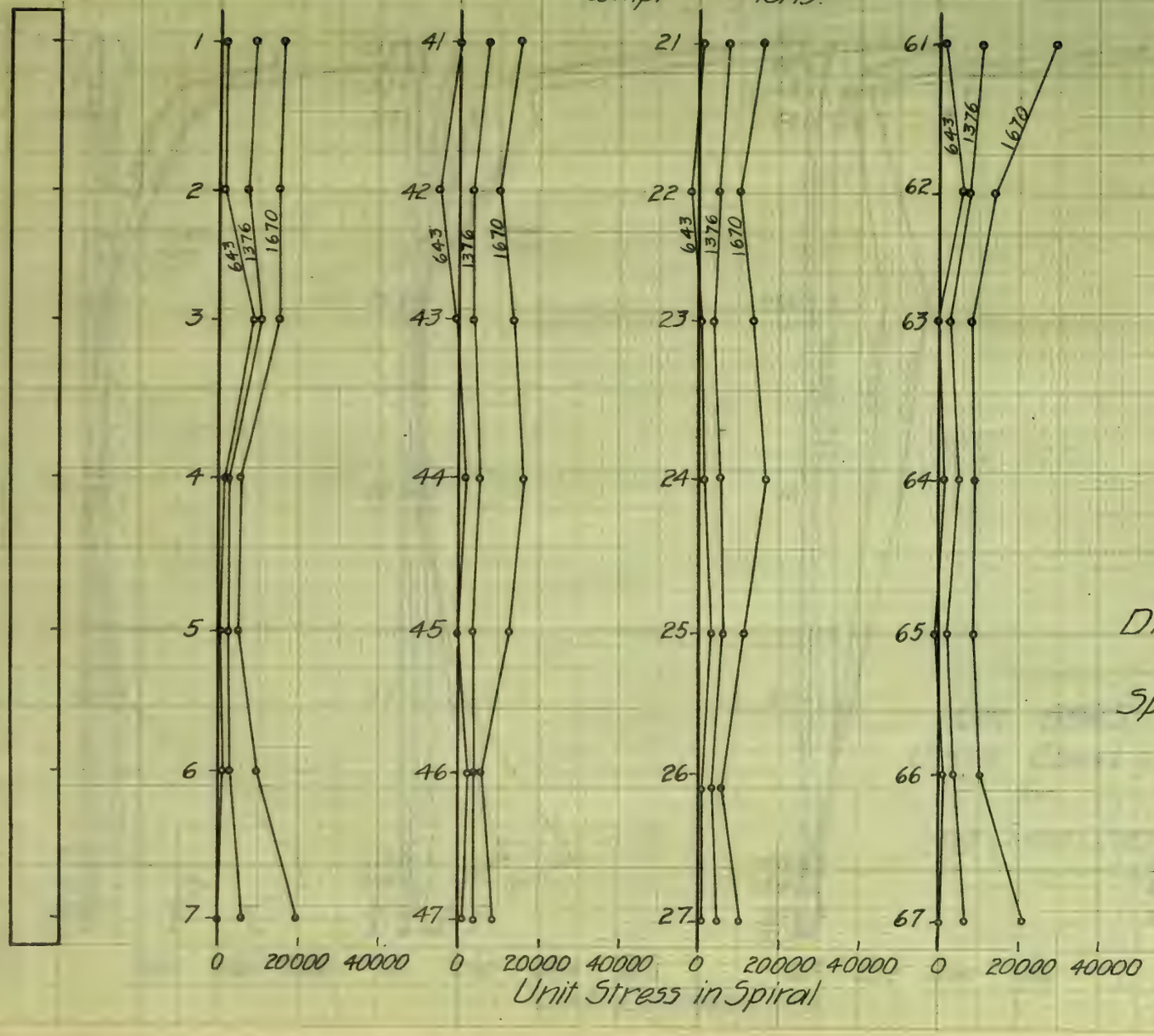

West
East
North
South
Tens ← → Comp.
101
102
103
104
105
106
107
141
142
143
144
145
146
147
121
122
123
124
125
126
127
161
162
163
164
165
166
167
P.I.
2160
1600
1330
1100
887
621
222
0
.002
.004
.006
.008
Unit Deformations
COL. 8920
DISTR. CURVES
for
Long. Gage Lines.
174


West
East
North
South
Tens. ← → Comp.
101
102
103
104
105
106
107
108
109
110
111
141
142
143
144
145
146
147
148
149
150
151
121
122
123
124
125
126
127
128
129
130
131
161
162
163
164
165
166
167
168
169
170
171
1423
1780
1985
P.I.
1160
880
623
223
COL. 8921
DISTR. CURVES
for
Long. Gage Lines.
0 .002 .004 .006 .008
Unit Deformations




West
East
North
South
Comp →
1100
1376
643
229
1670
1610
P.I.
101
102
103
104
105
106
107
141
142
143
144
145
146
147
121
122
123
124
125
126
127
161
162
163
164
165
166
167
0
.002
.004
.006
.008
0010
Unit Deformations
Col. 8924
Distr. Curves
for
Long. Gage Lines.
176



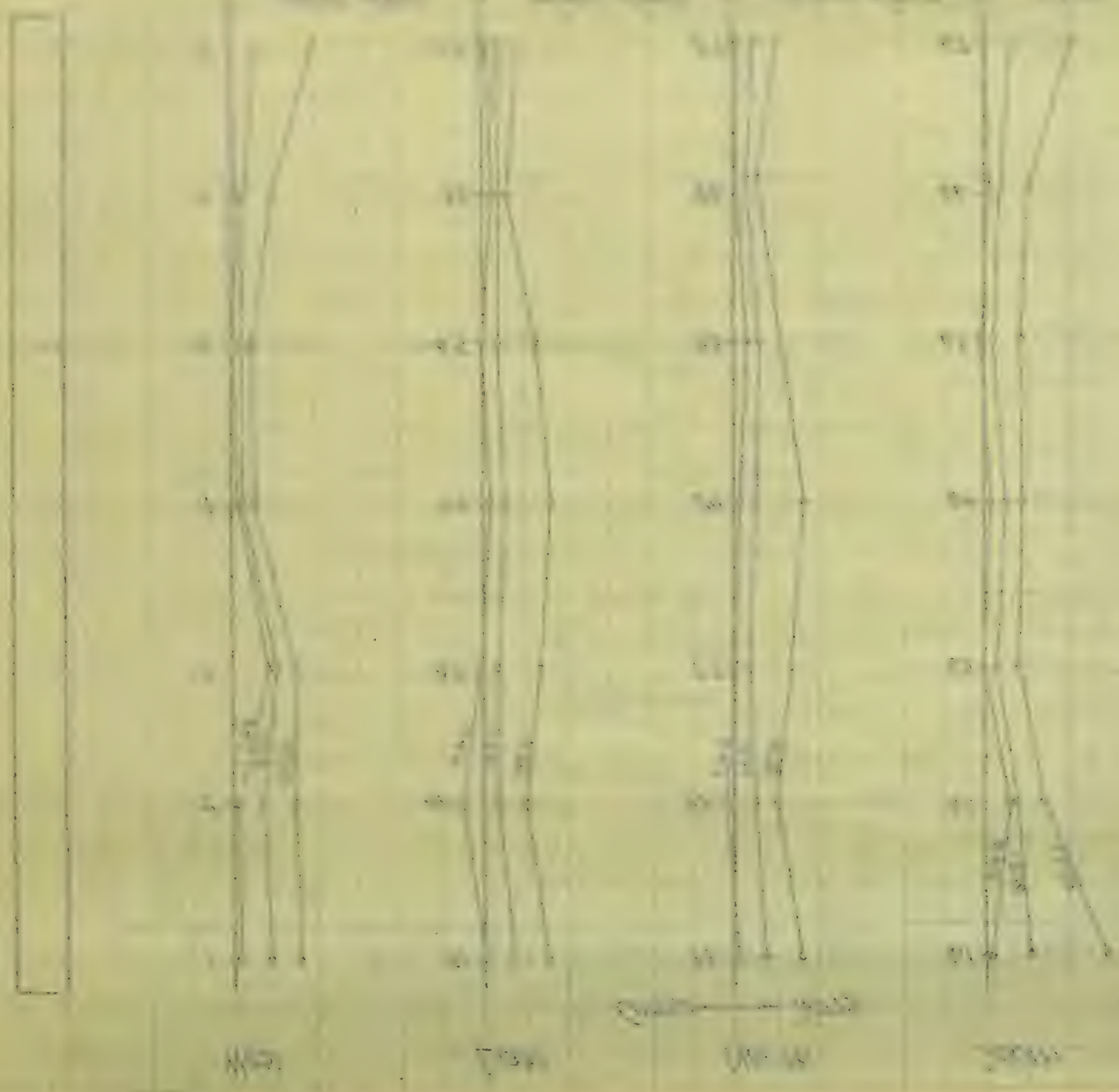


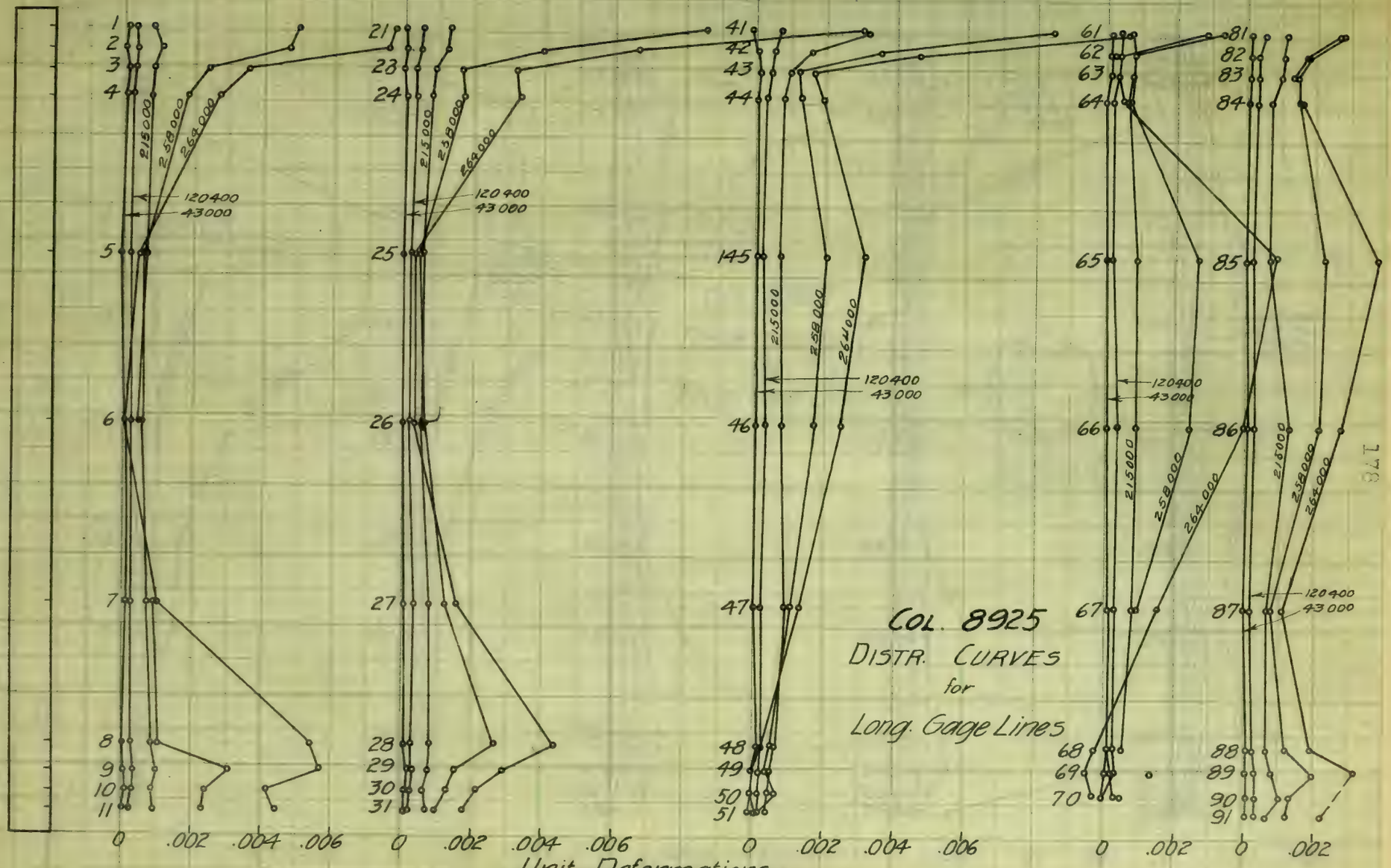
Col. 8924

Distr. Curves

for

Spiral Gage Lines.





COL. 8925

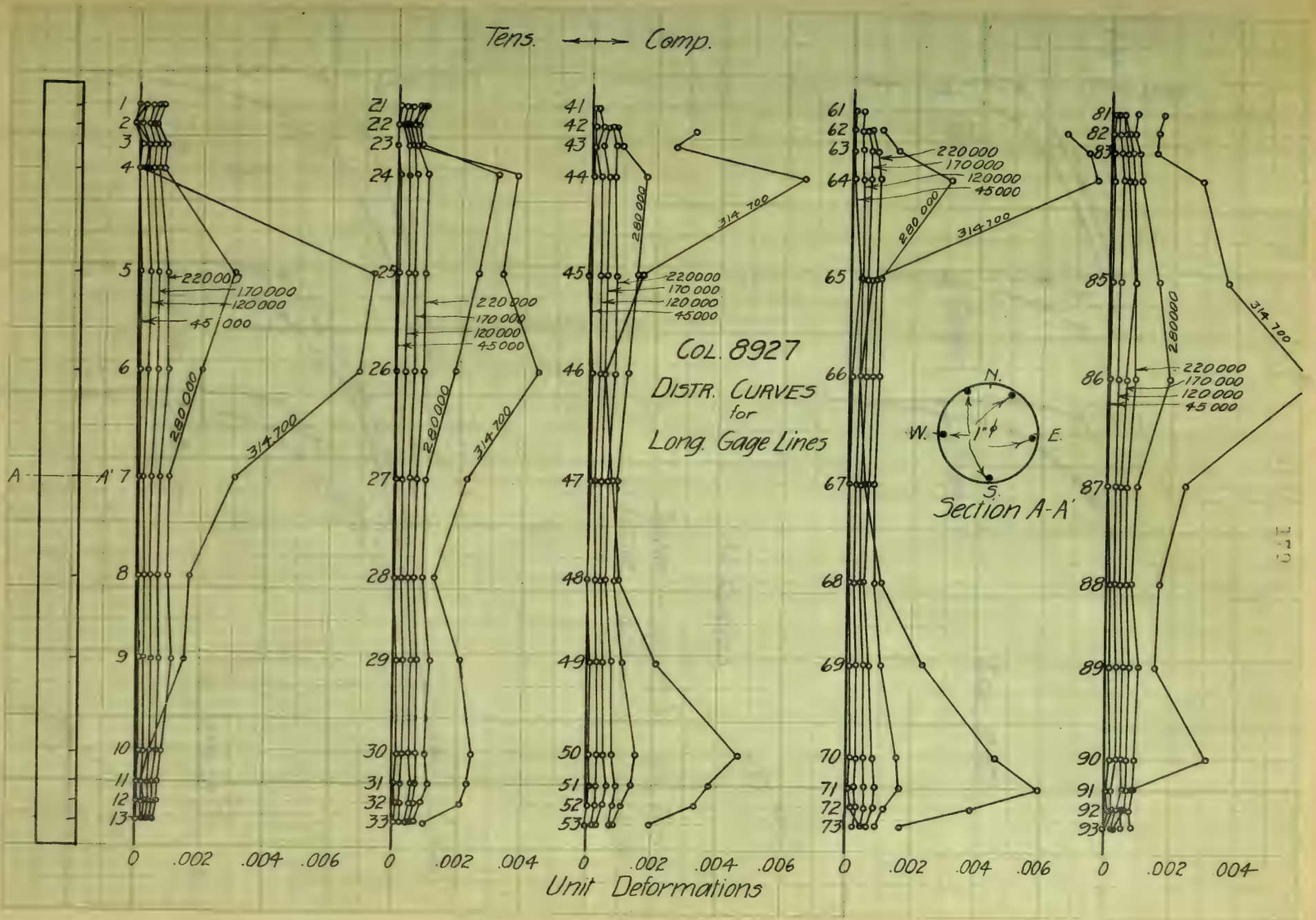
DISTR. CURVES

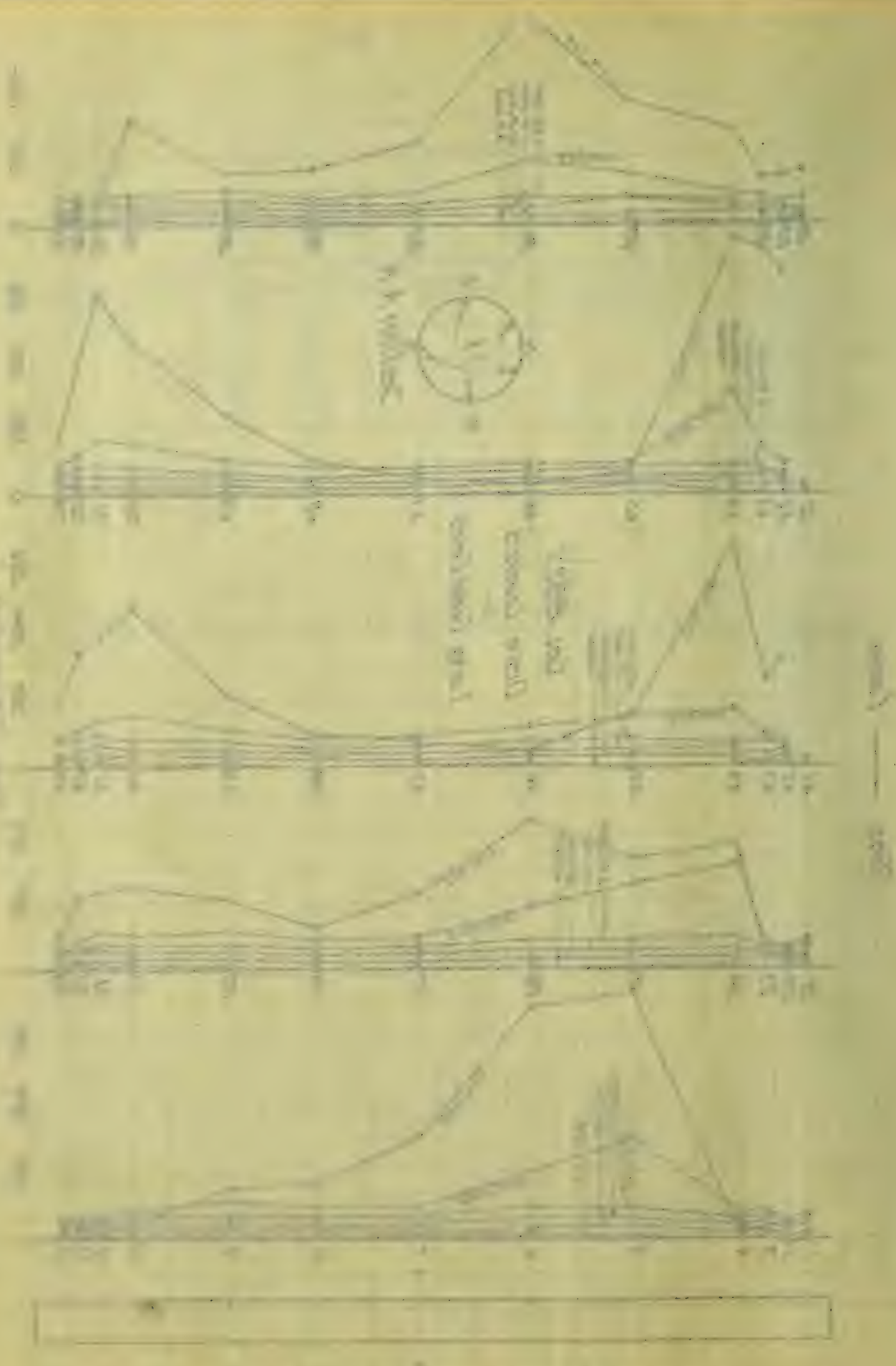
for

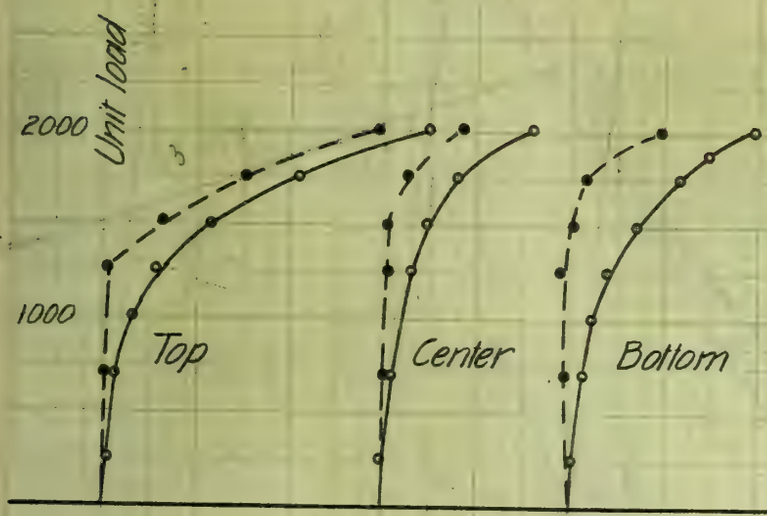
Long. Gage Lines

178




Tens. ← → Comp.
A
A'
220000
170000
120000
45000
280000
314700
COL. 8927
DISTR. CURVES
for
Long. Gage Lines
N.
W.
E.
S.
Section A-A'
0
.002
.004
.006
Unit Deformations

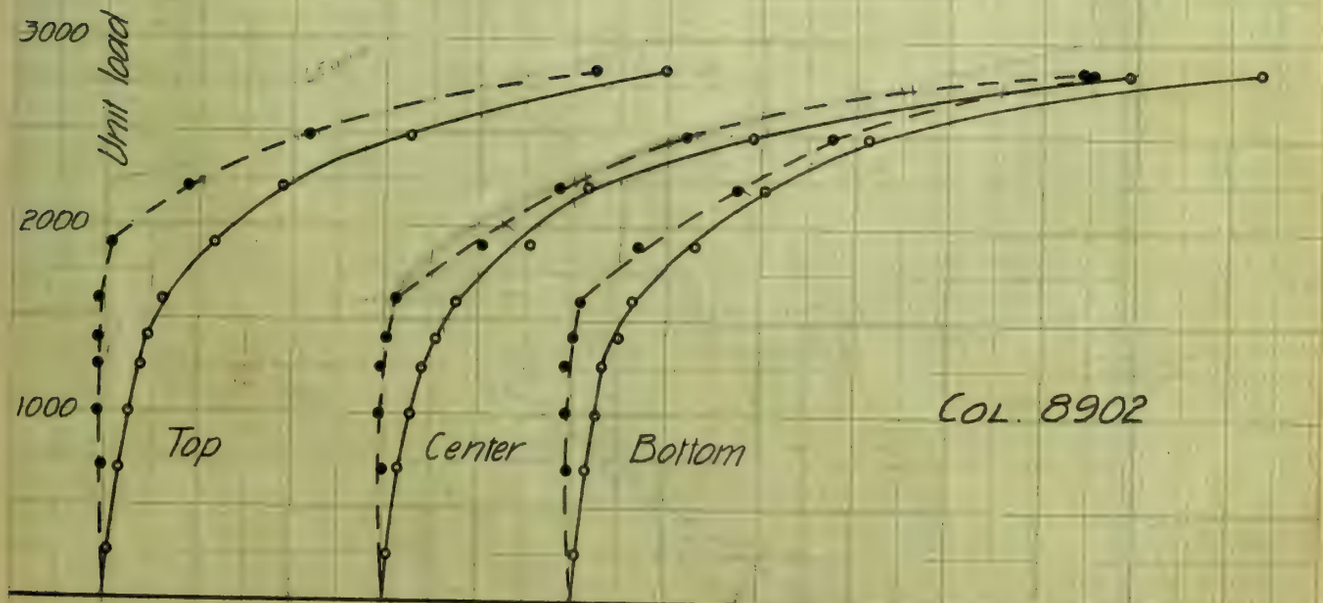




COL. 8901

AV. CURVES

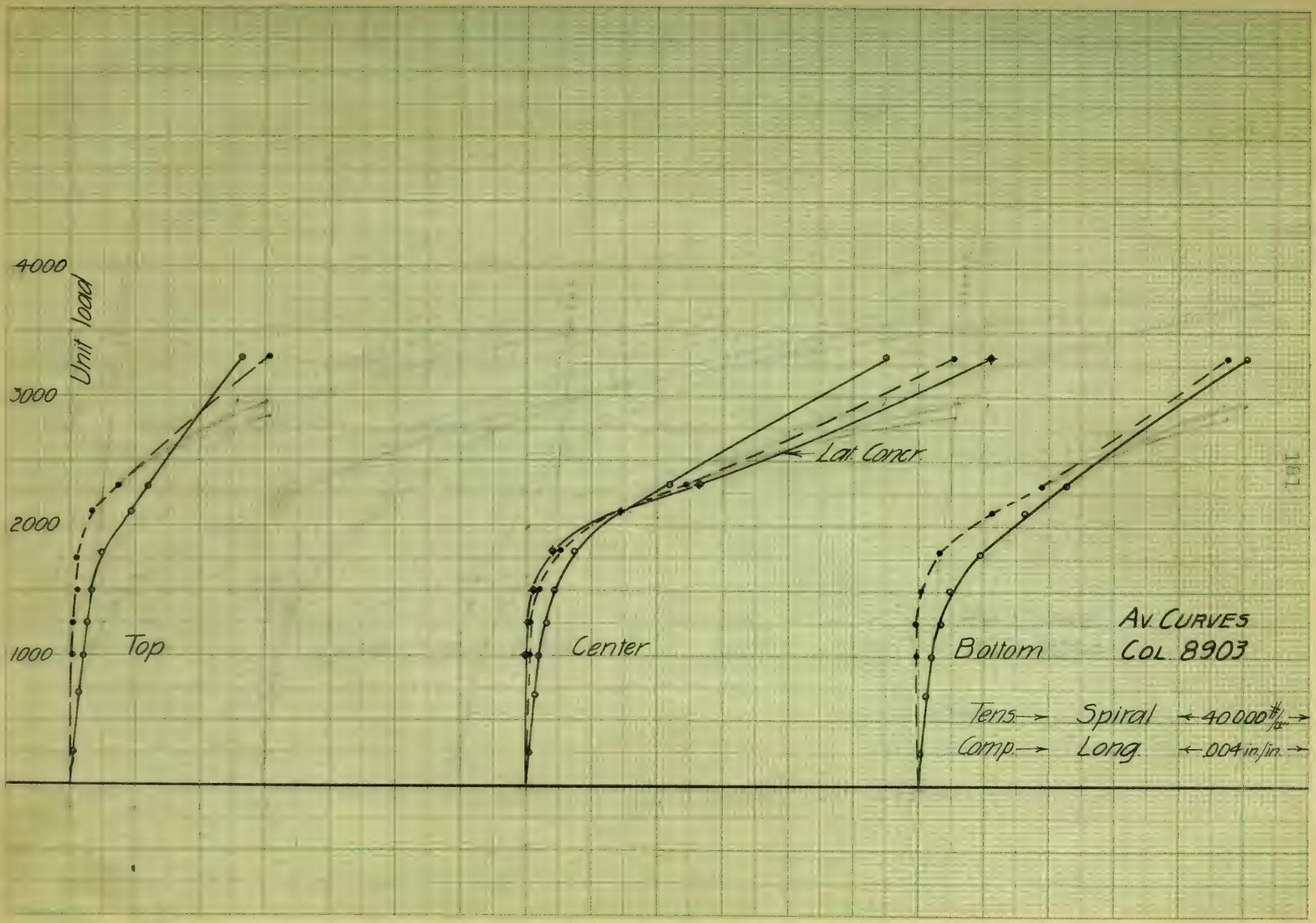
• Spiral ← 40000 #/in² → → Tens.
○ Long. ← .004 in./in. → → Comp



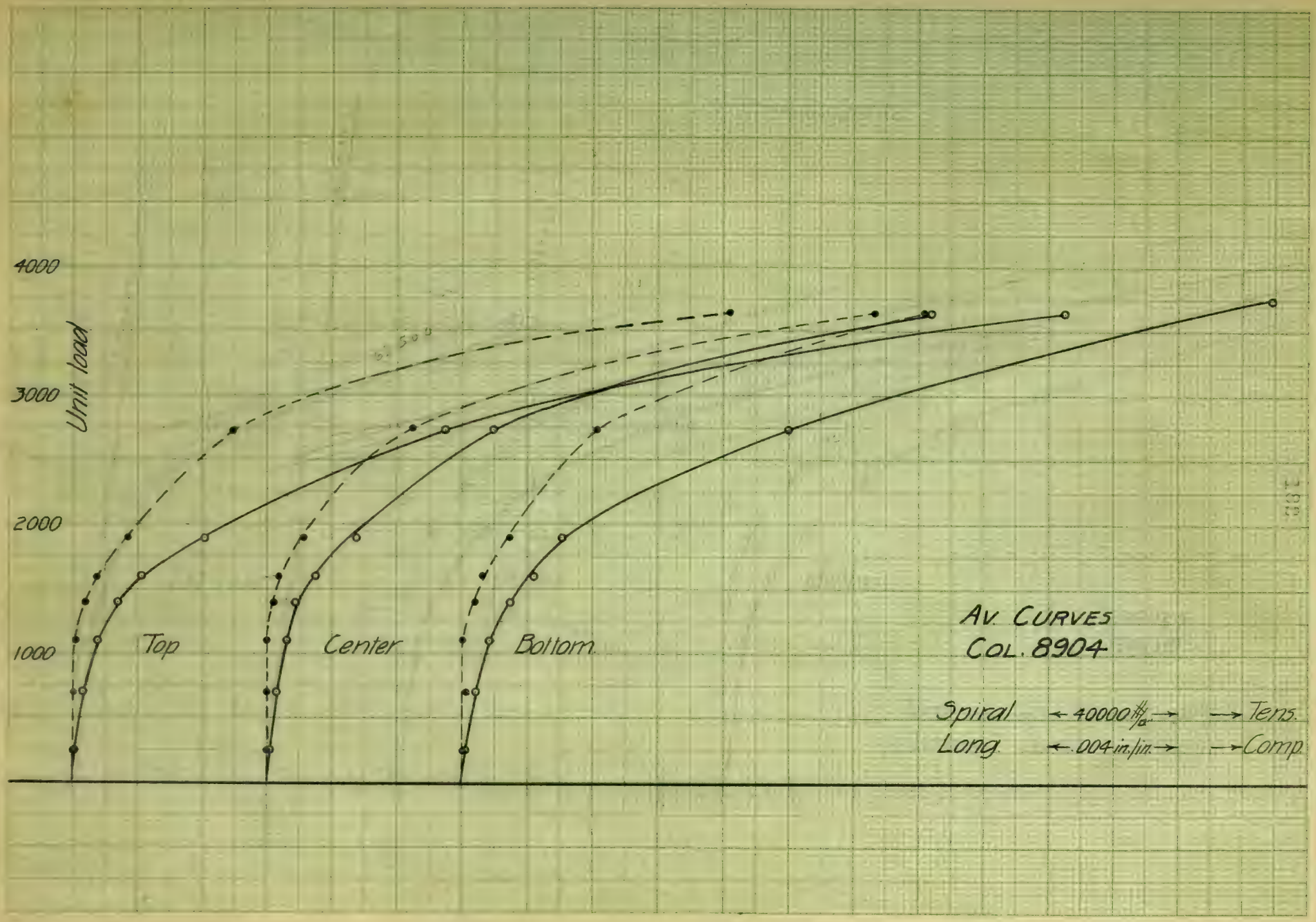
COL. 8902



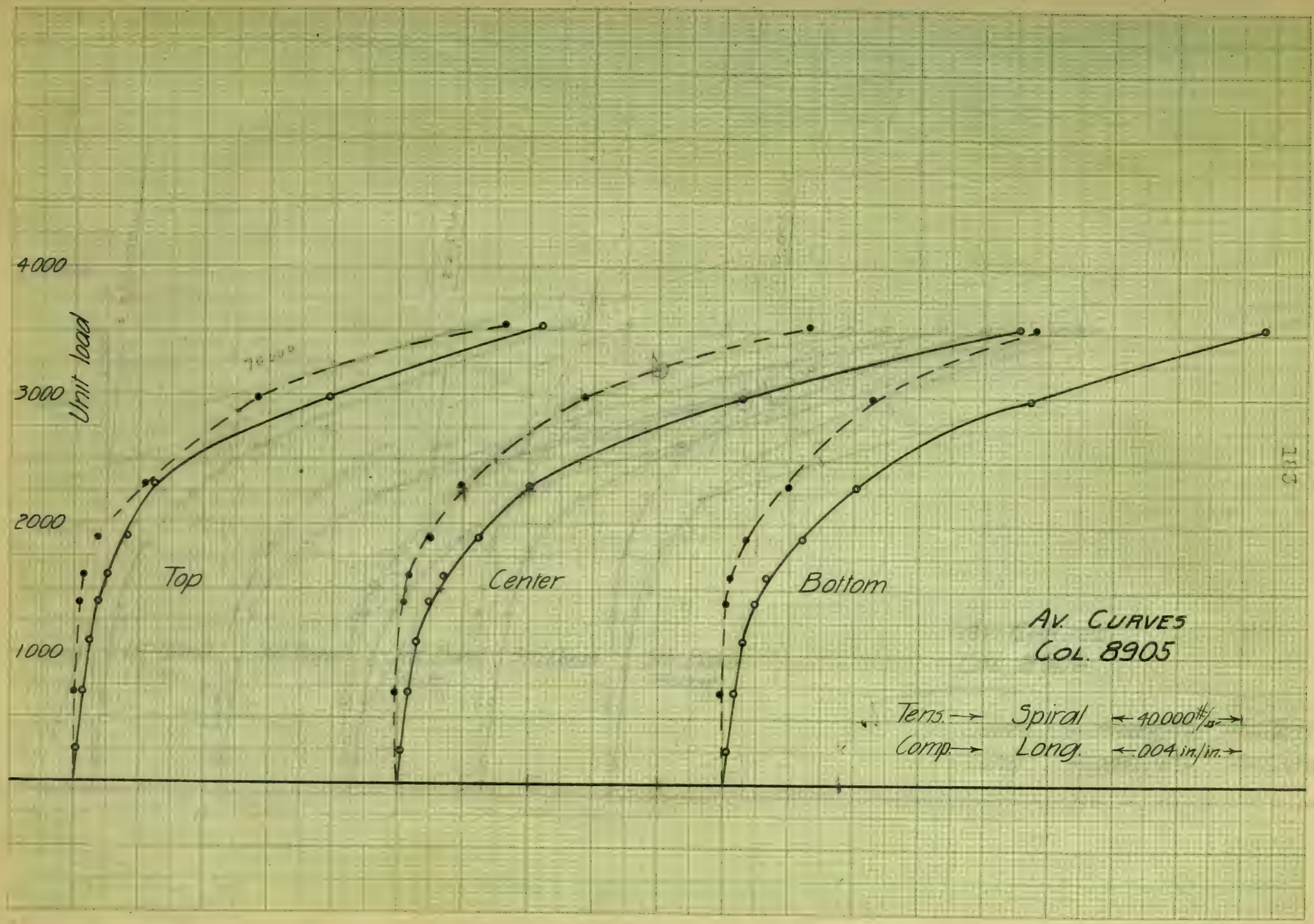


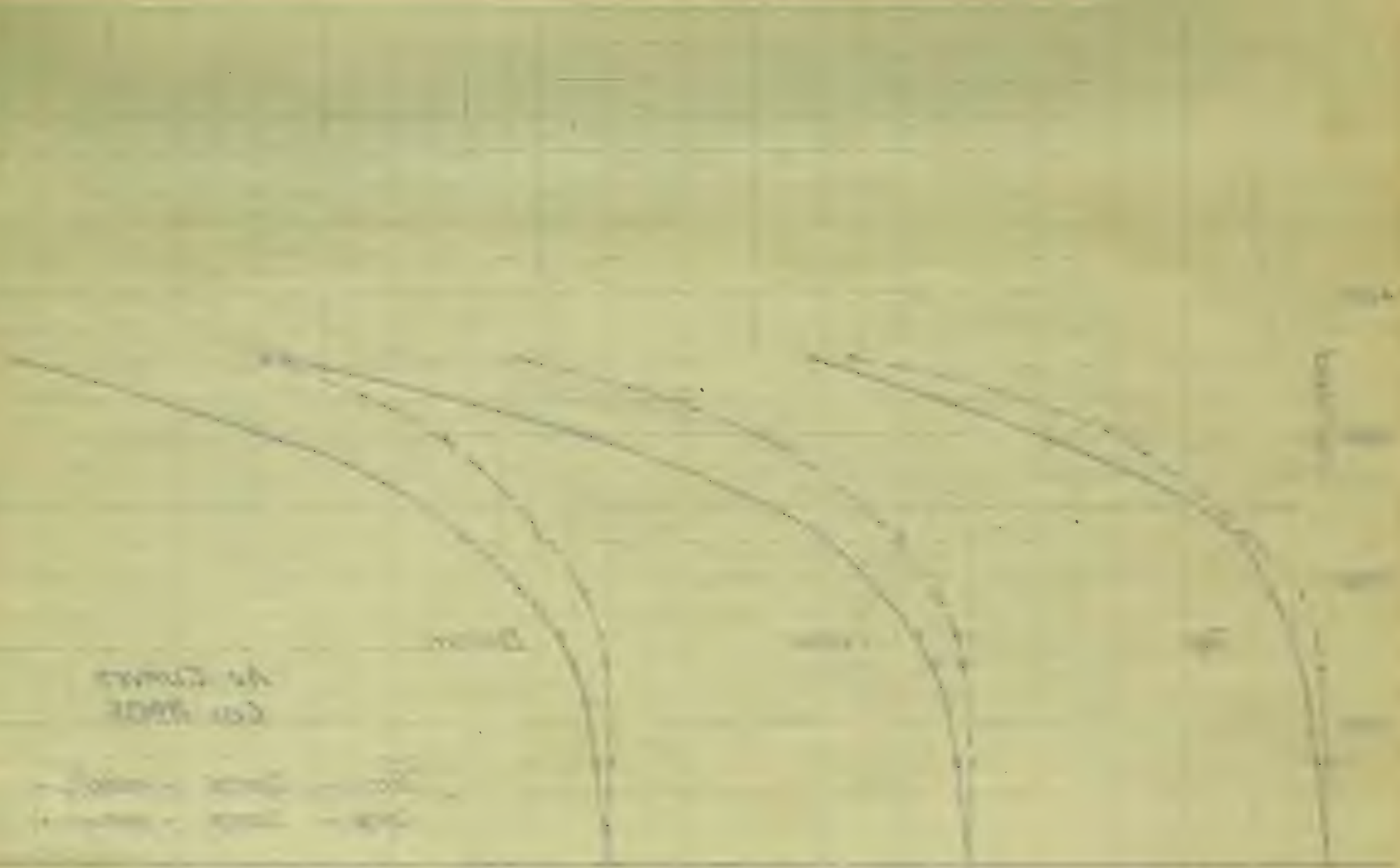

4000
3000
2000
1000
Unit load
Top
Center
Bottom
Lat. Concr.
Av. Curves
Col 8903
Tens. → Spiral ← 40000 #/in. →
Comp. → Long. ← .004 in./in. →

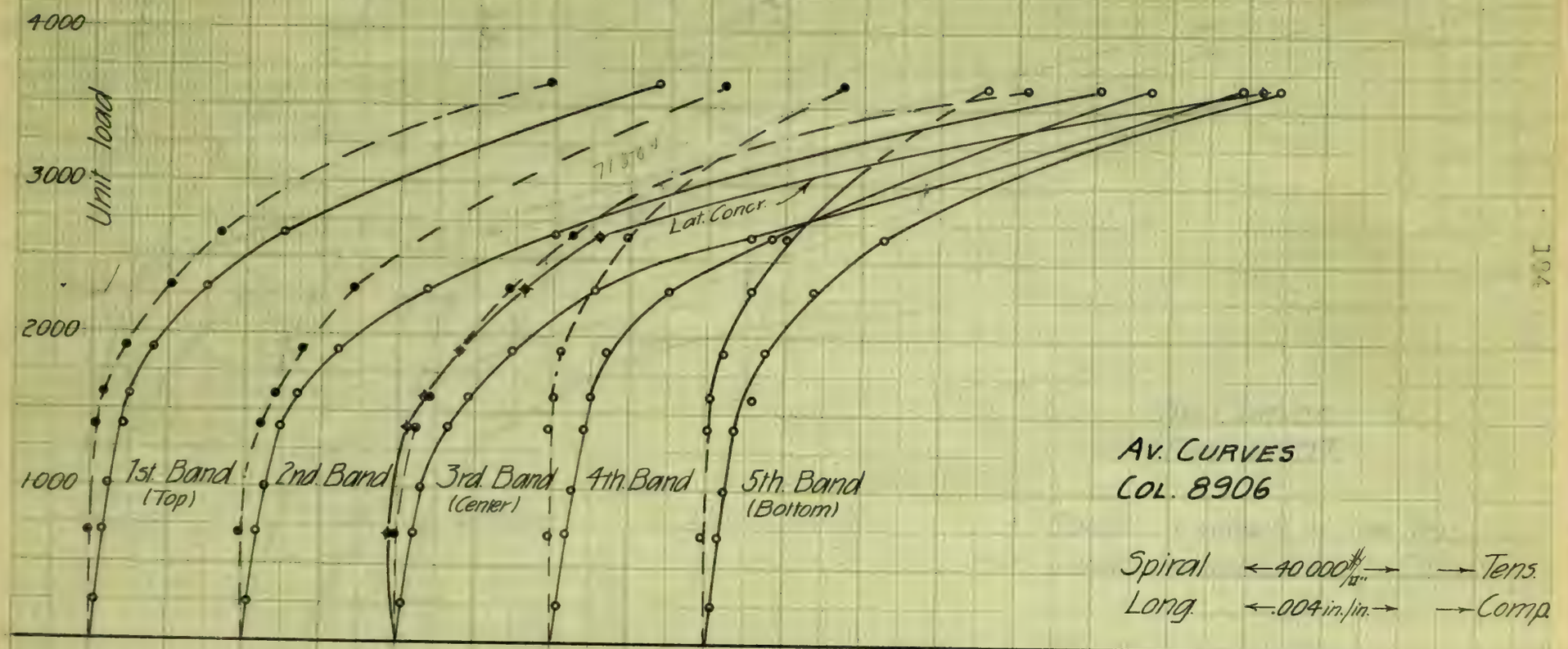


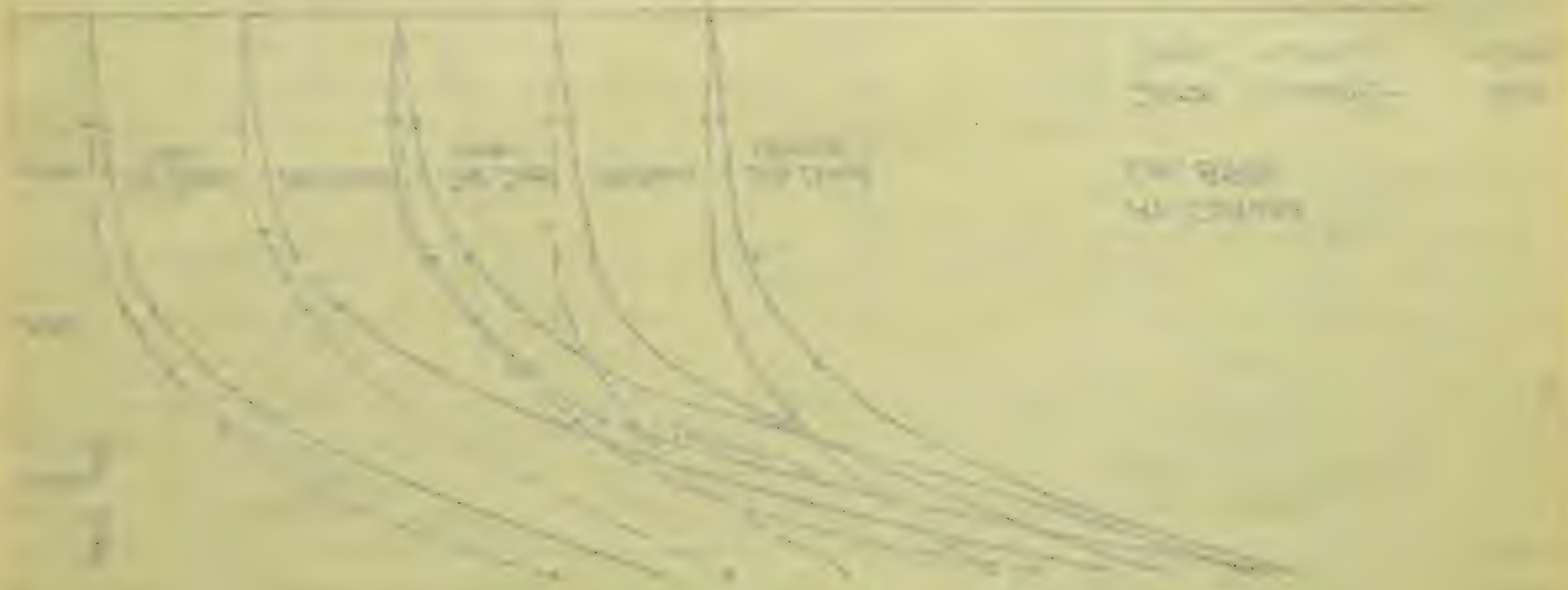

4000
3000
2000
1000
Unit load
Top
Center
Bottom
Av. Curves
Col. 8904
Spiral ← 40000 #/□" → → Tens.
Long ← .004 in./in. → → Comp.

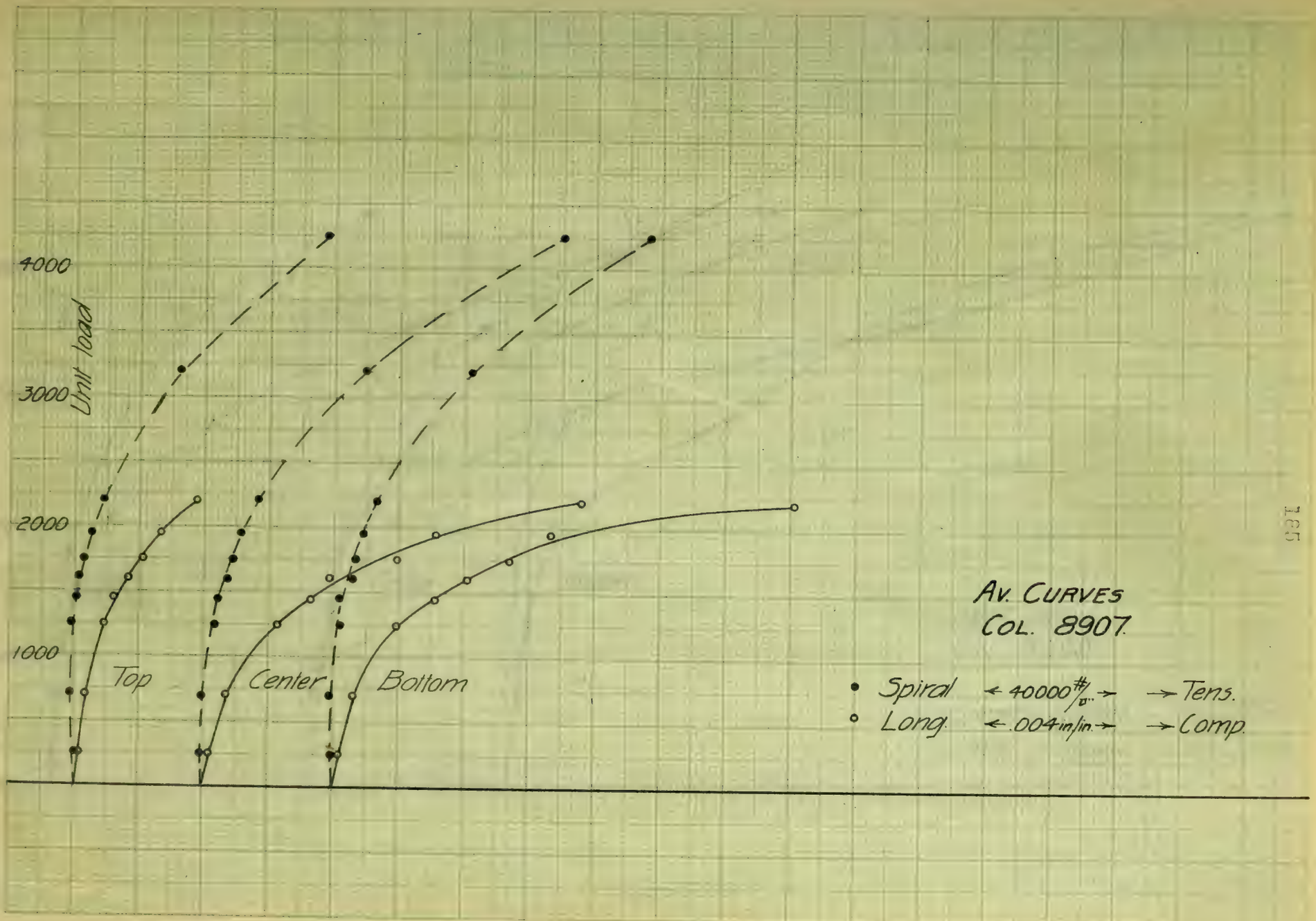



4000
3000
2000
1000
Unit load
Top
Center
Bottom
Av. Curves
Col. 8905
Tens. → Spiral ← 40000#/□"→
Comp. → Long. ← .004 in./in. →

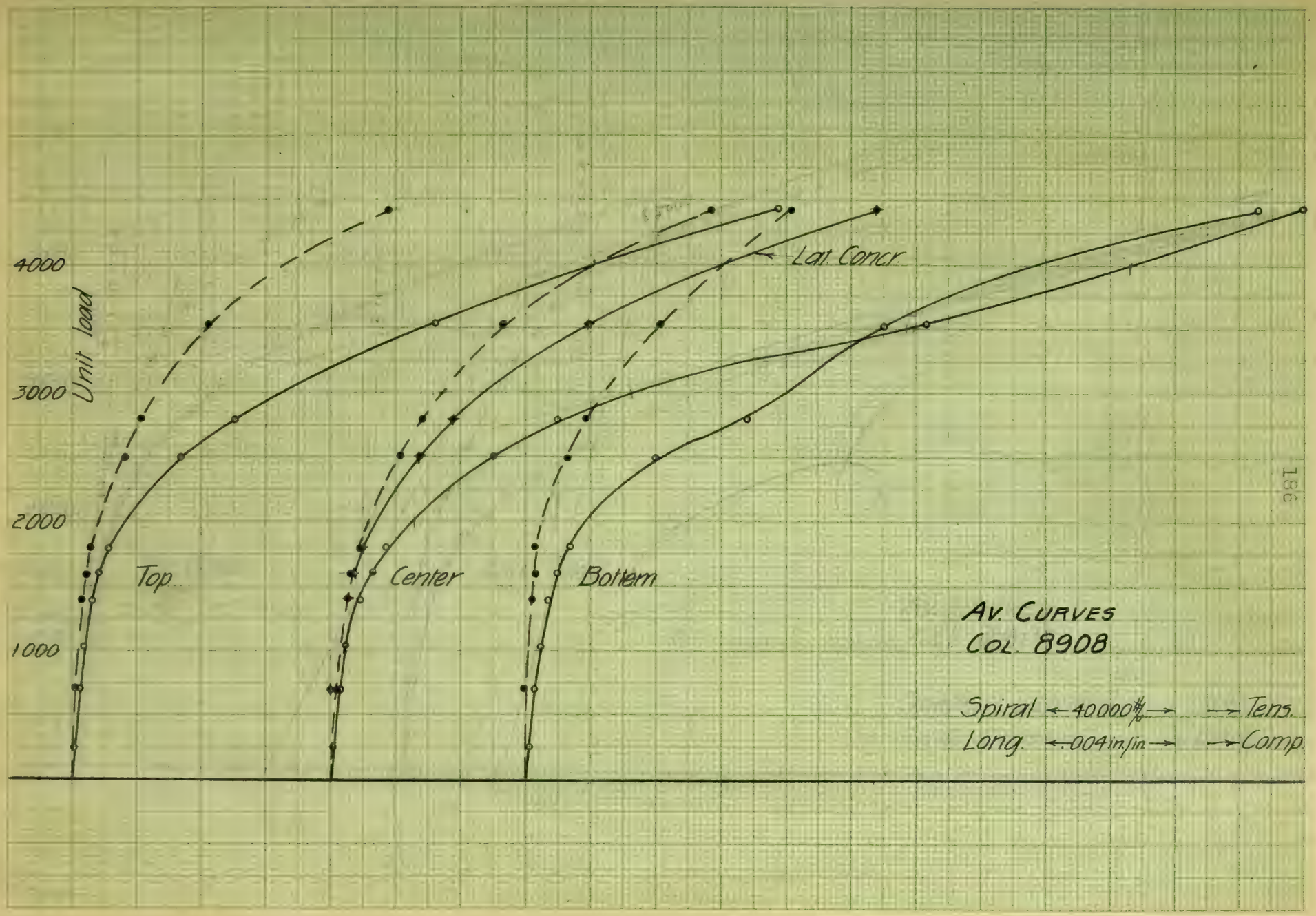


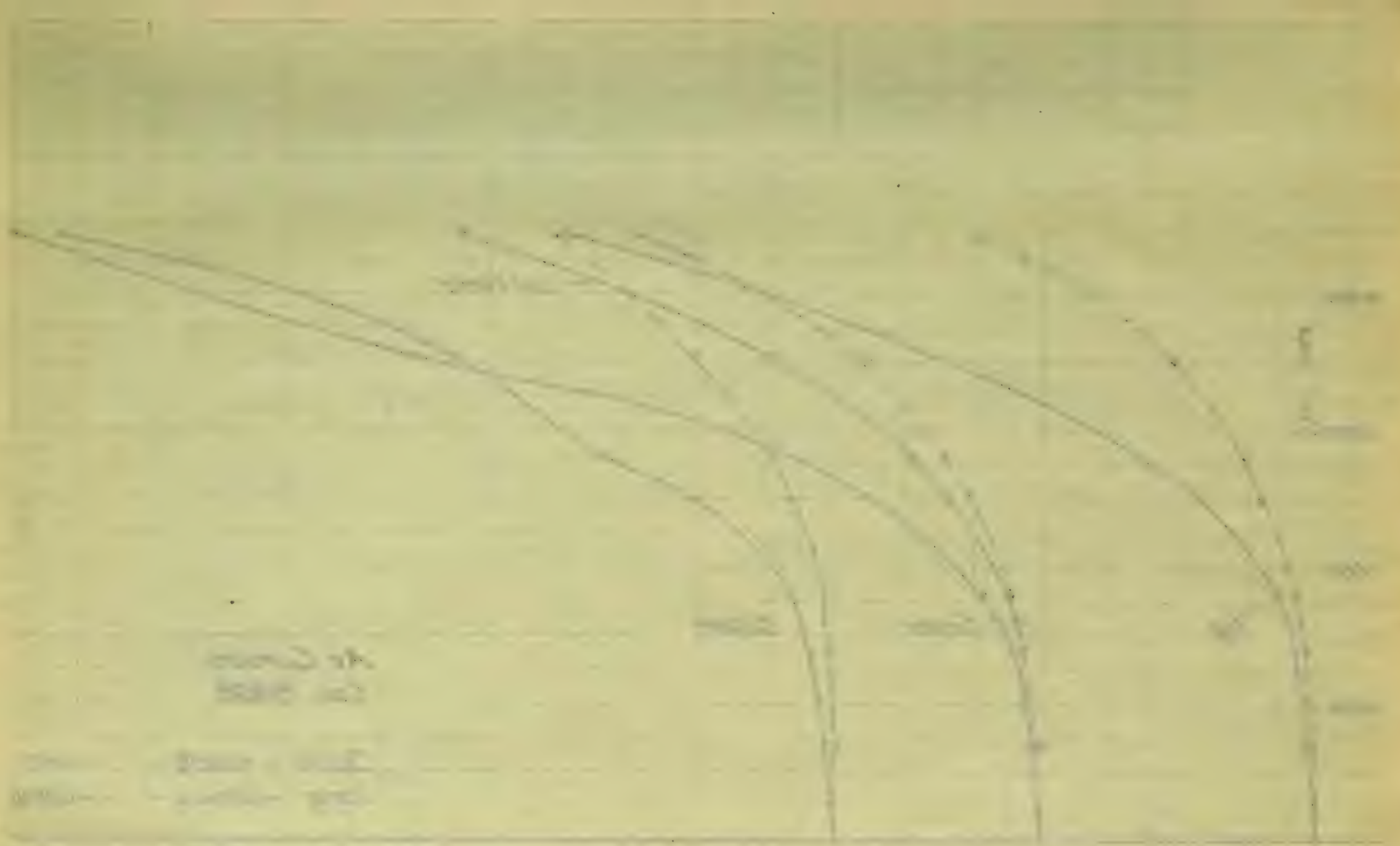

4000
3000
2000
1000
Unit load
Lat. Concr.
1st. Band (Top)
2nd. Band
3rd. Band (Center)
4th. Band
5th. Band (Bottom)
Av. Curves
Col. 8906
Spiral ←40 000 #/sq. in.→ →Tens.
Long. ←.004 in./in.→ →Comp.

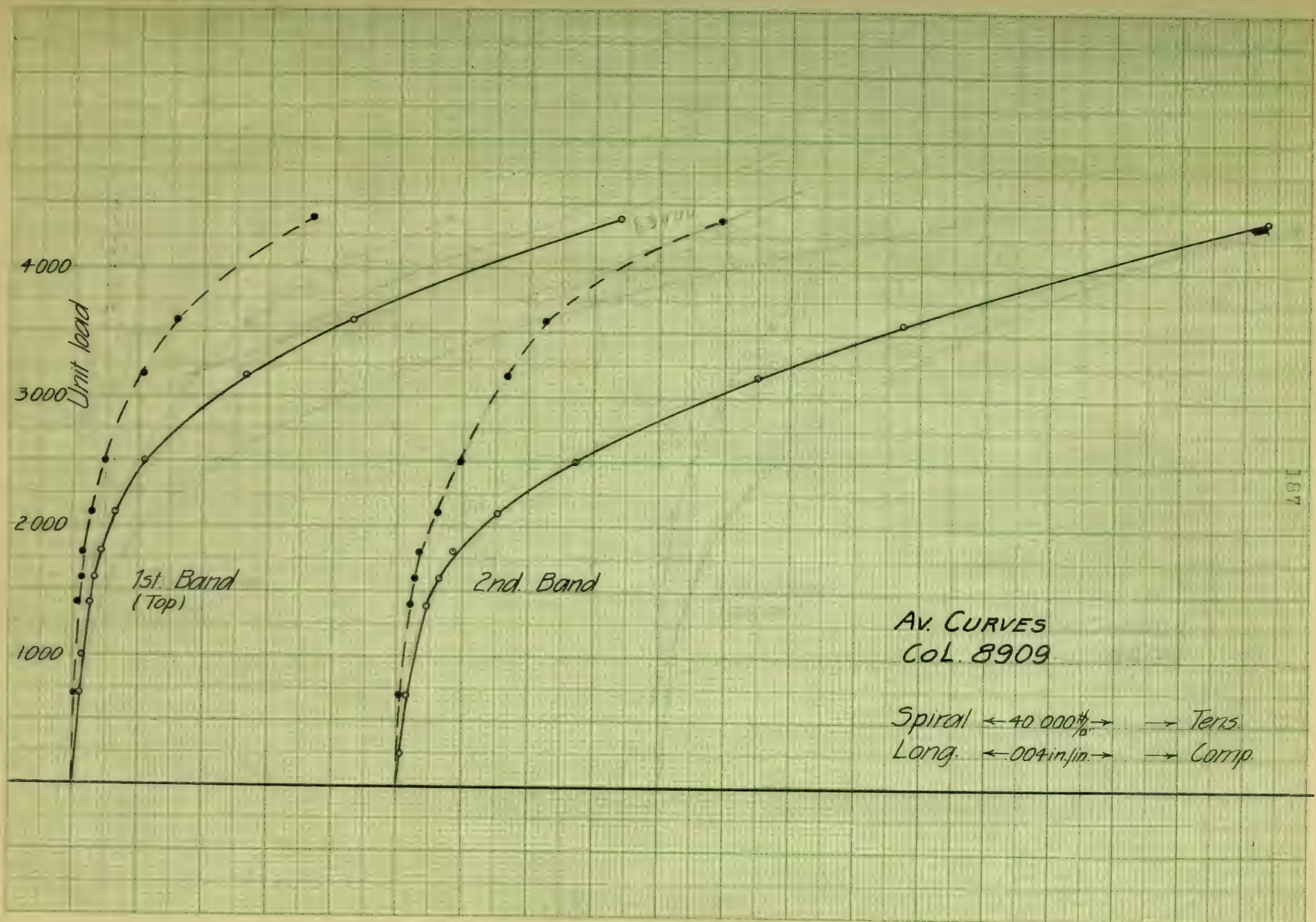


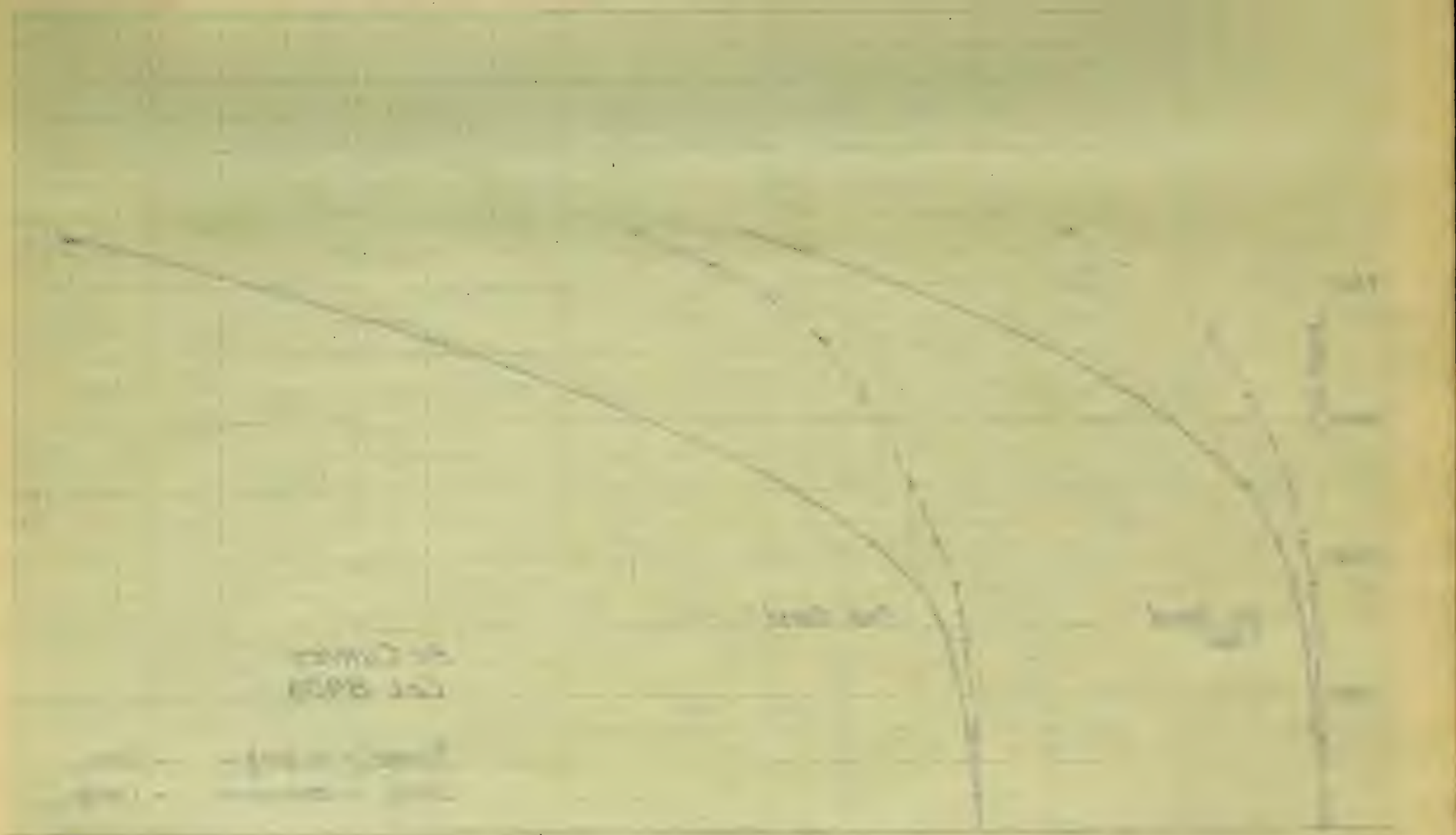

4000
3000
2000
1000
Unit load
Top
Center
Bottom
Av. Curves
Col. 8907.
Spiral ← 40000 #/□" → → Tens.
Long. ← .004 in/in → → Comp.

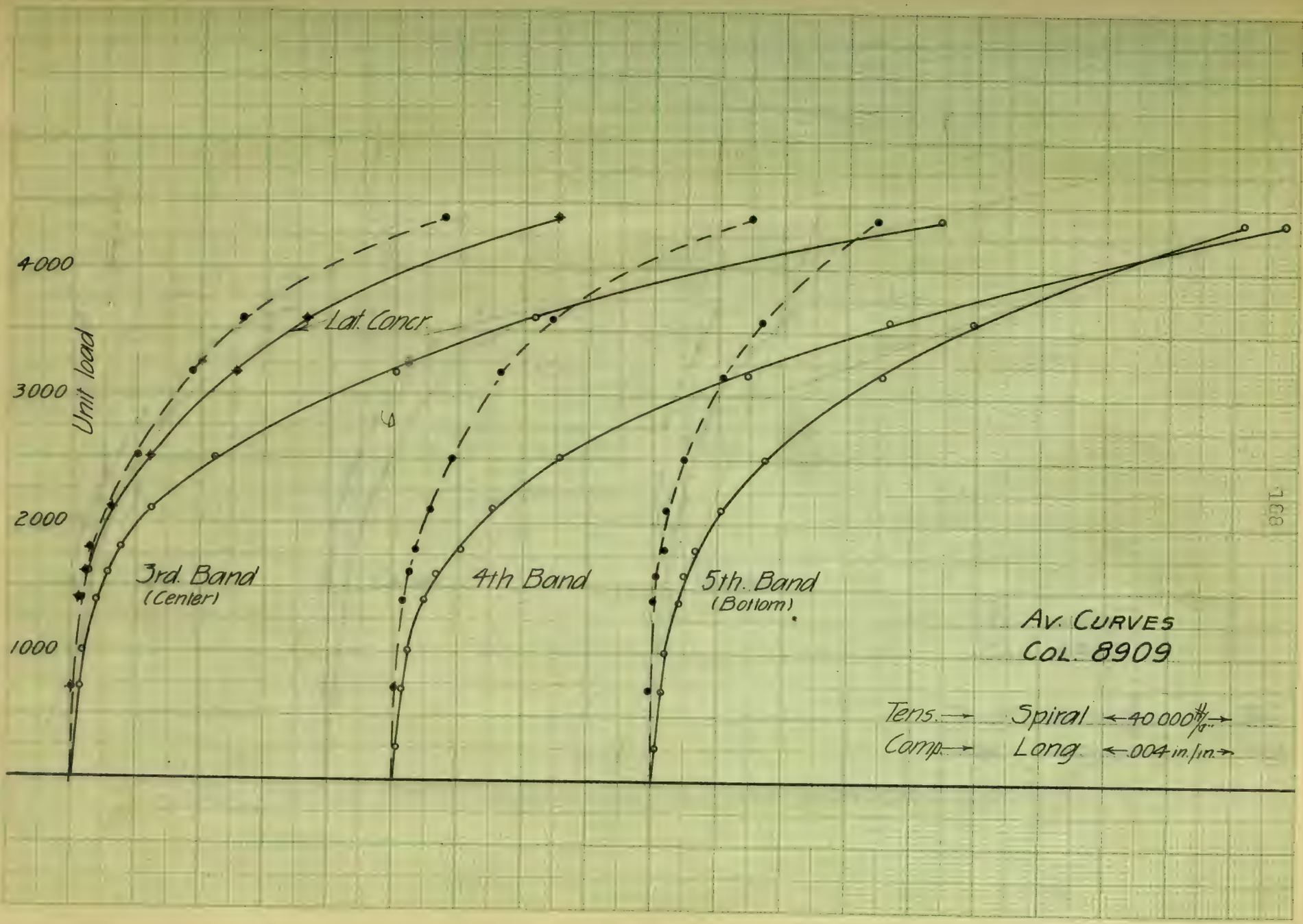


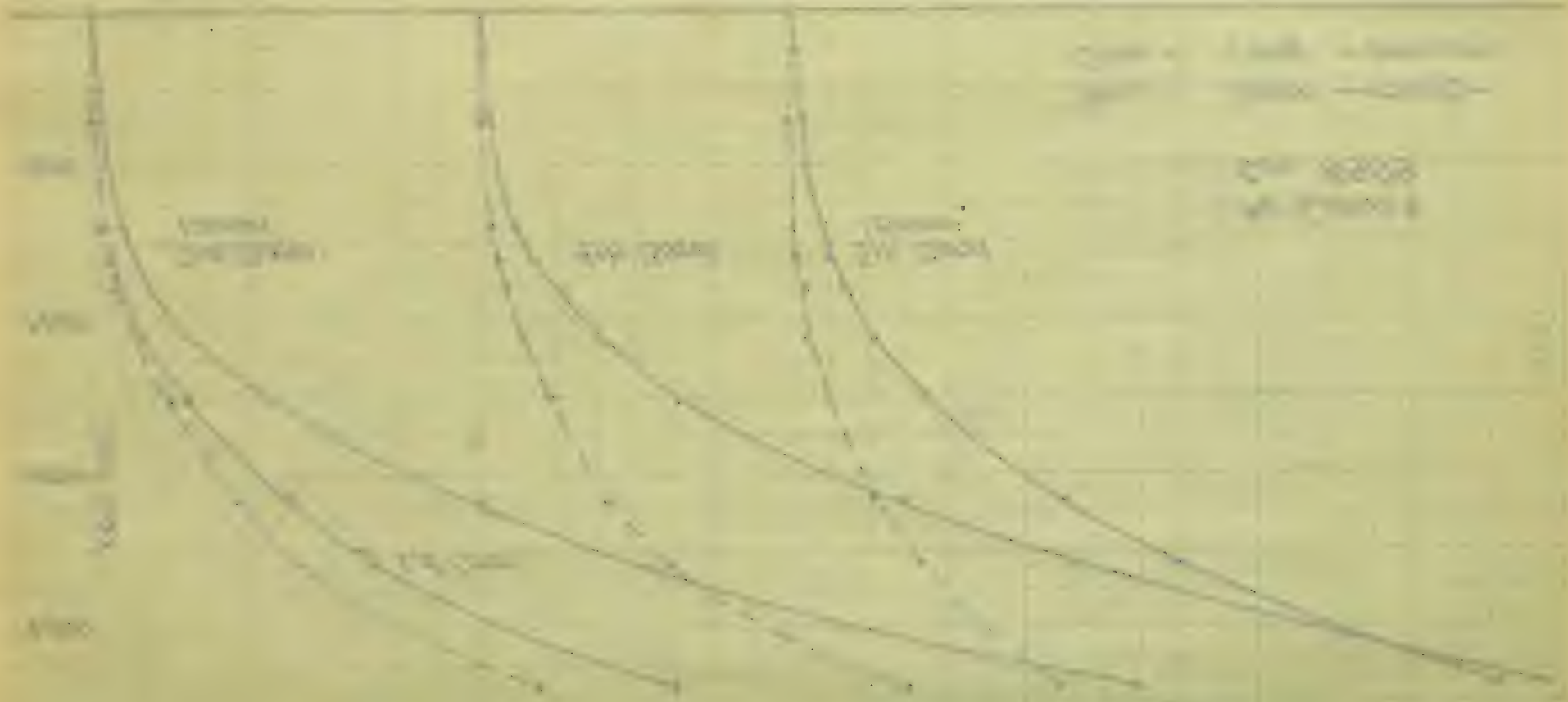

4000
3000
2000
1000
Unit load
Lat. Concr.
Top
Center
Bottom
AV. CURVES
COL. 8908
Spiral ← 40000# → → Tens.
Long. ← .004 in./in. → → Comp.

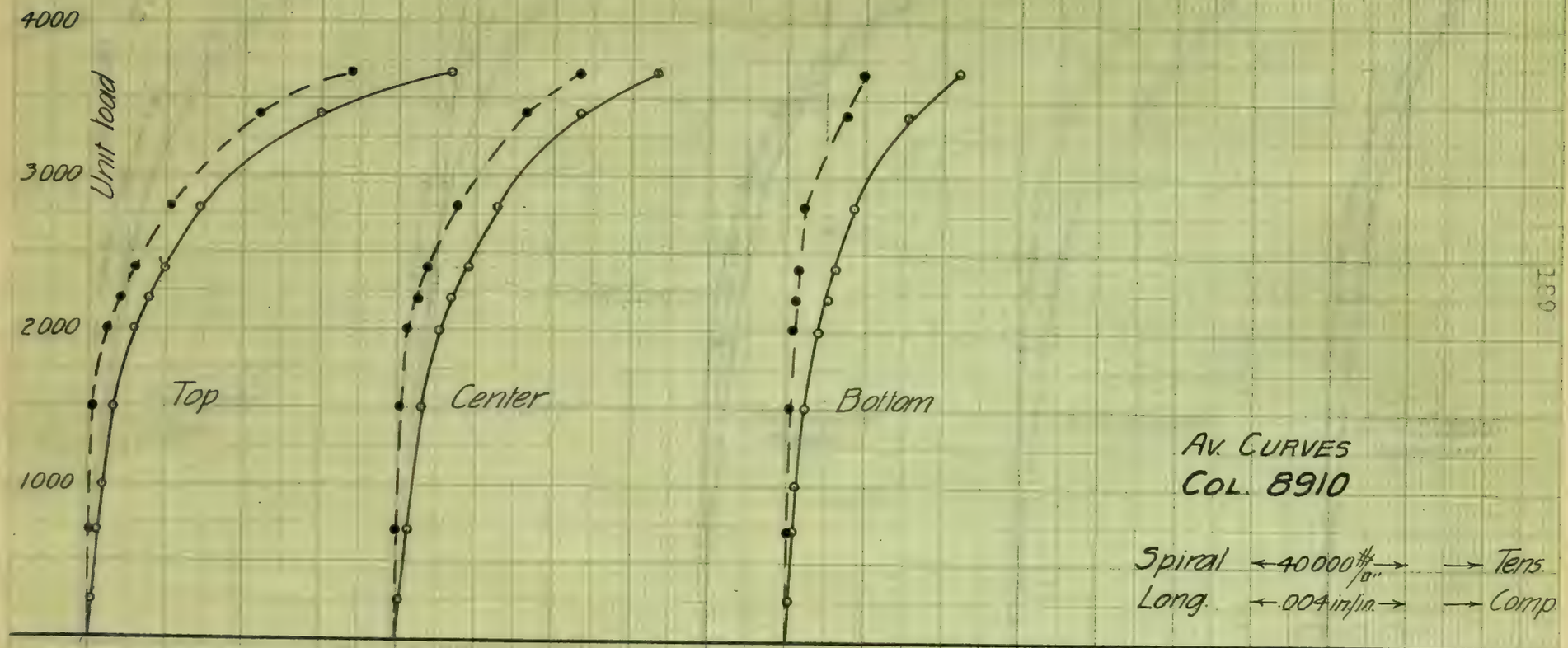


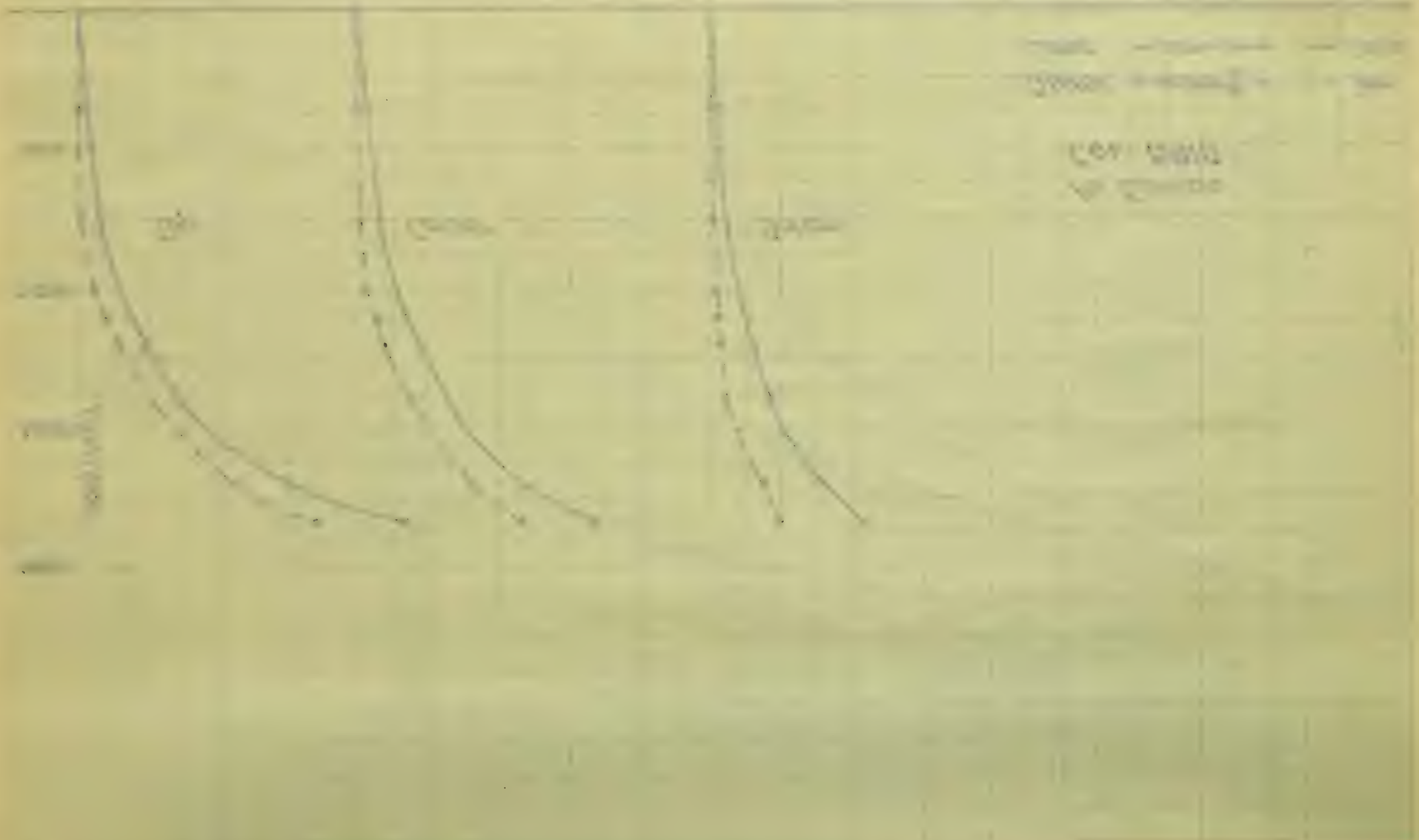

4000
3000
2000
1000
Unit load
1st. Band
(Top)
2nd. Band
Av. Curves
Col. 8909
Spiral ← 40 000 #/in² → → Tens.
Long. ← .004 in./in. → → Comp.
187

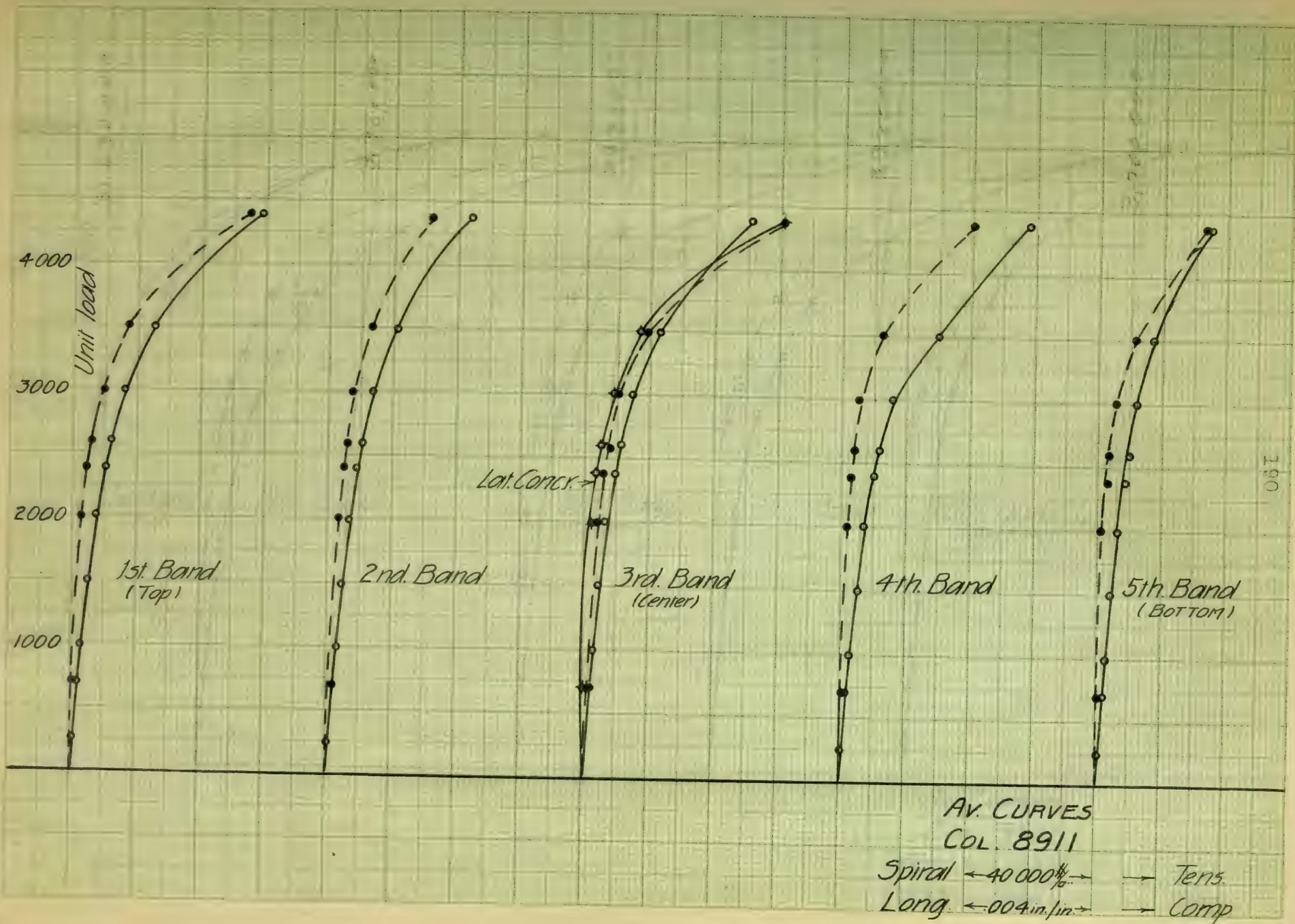



4000
3000
2000
1000
Unit load
Lat. Concr.
3rd. Band
(Center)
4th Band
5th. Band
(Bottom)
AV. CURVES
COL. 8909
Tens. → Spiral ← 40 000 #/□"→
Comp. → Long. ← .004 in./in.→
7C8

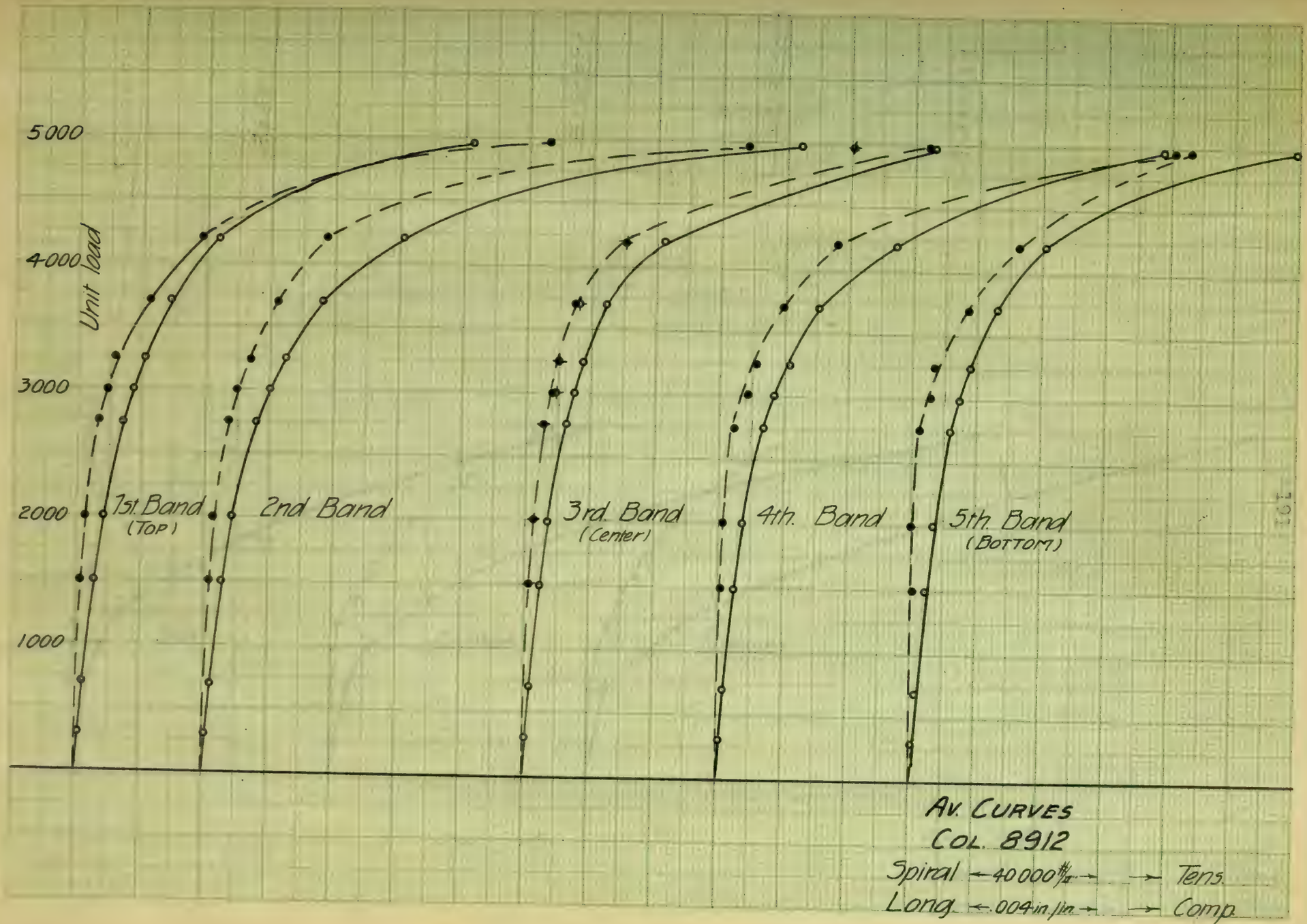


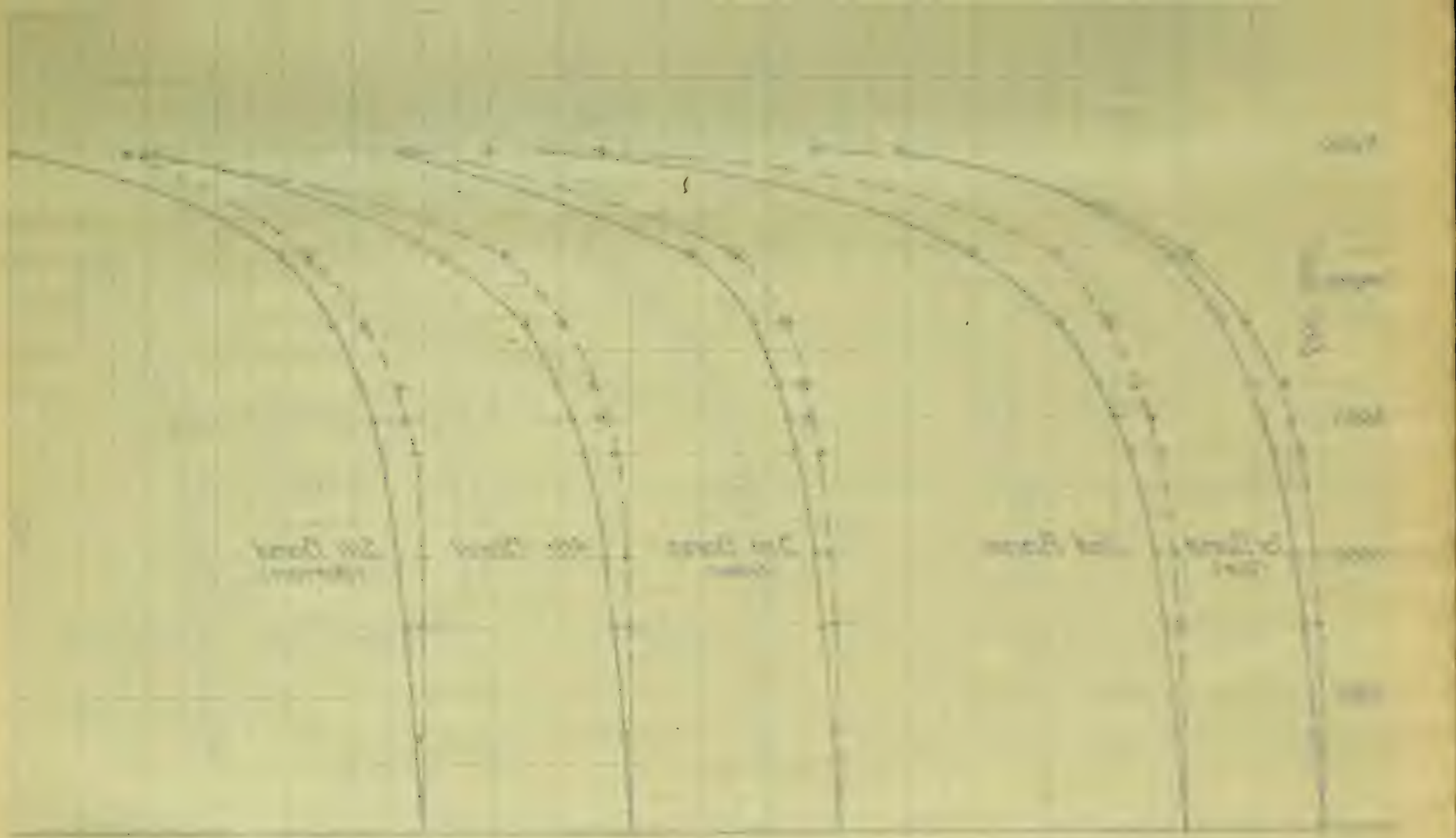

4000
3000
2000
1000
Unit load
Top
Center
Bottom
Av. Curves
Col. 8910
Spiral ← 40000 #/a" → → Tens.
Long. ← .004 in/in. → → Comp.

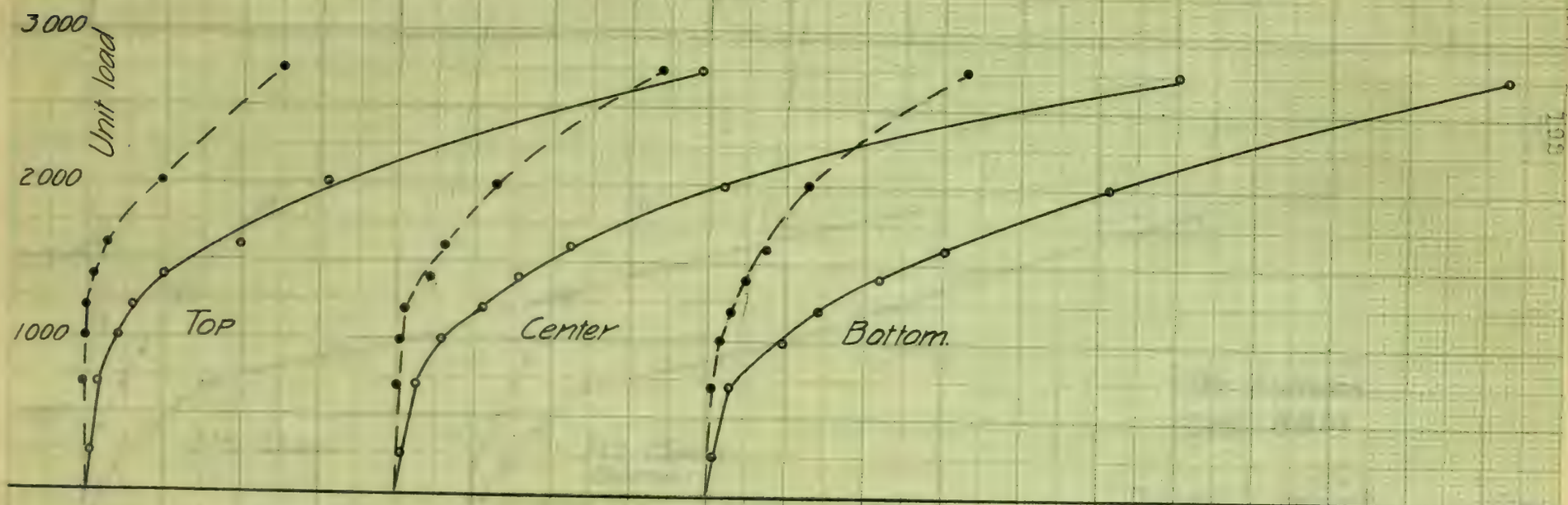



4000
3000
2000
1000
Unit load
1st. Band
(Top)
2nd. Band
Lat. Concr.
3rd. Band
(Center)
4th. Band
5th. Band
(Bottom)
Av. Curves
Col. 8911
Spiral ← 40 000 #/□" → — Tens.
Long. ← 004 in./in. → — Comp

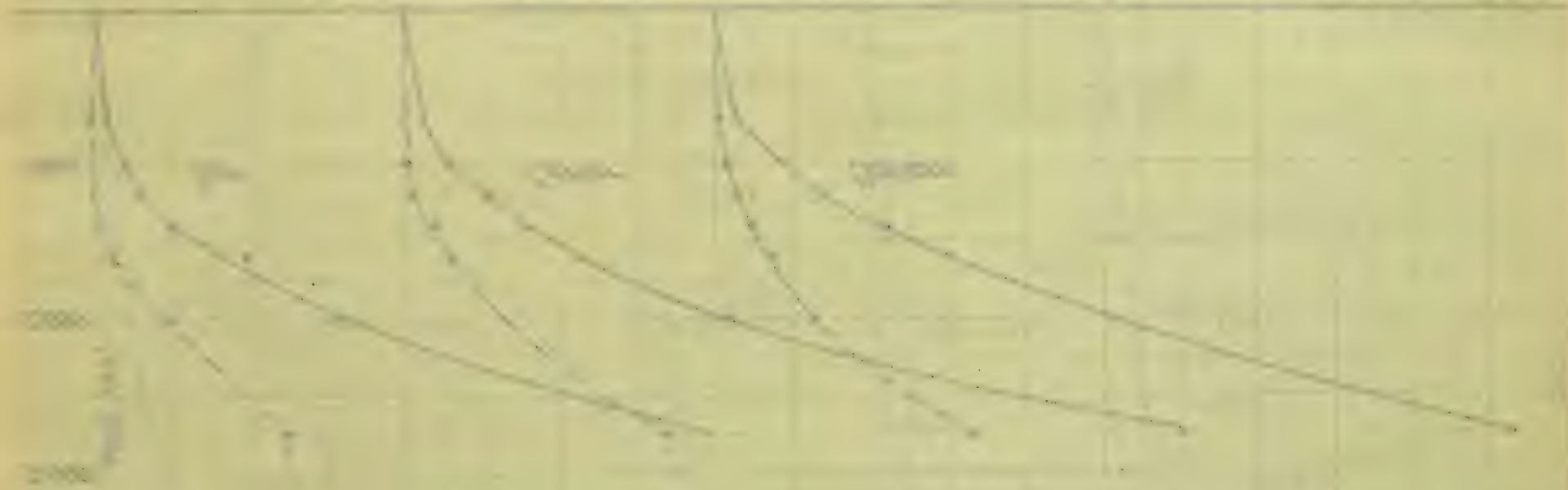


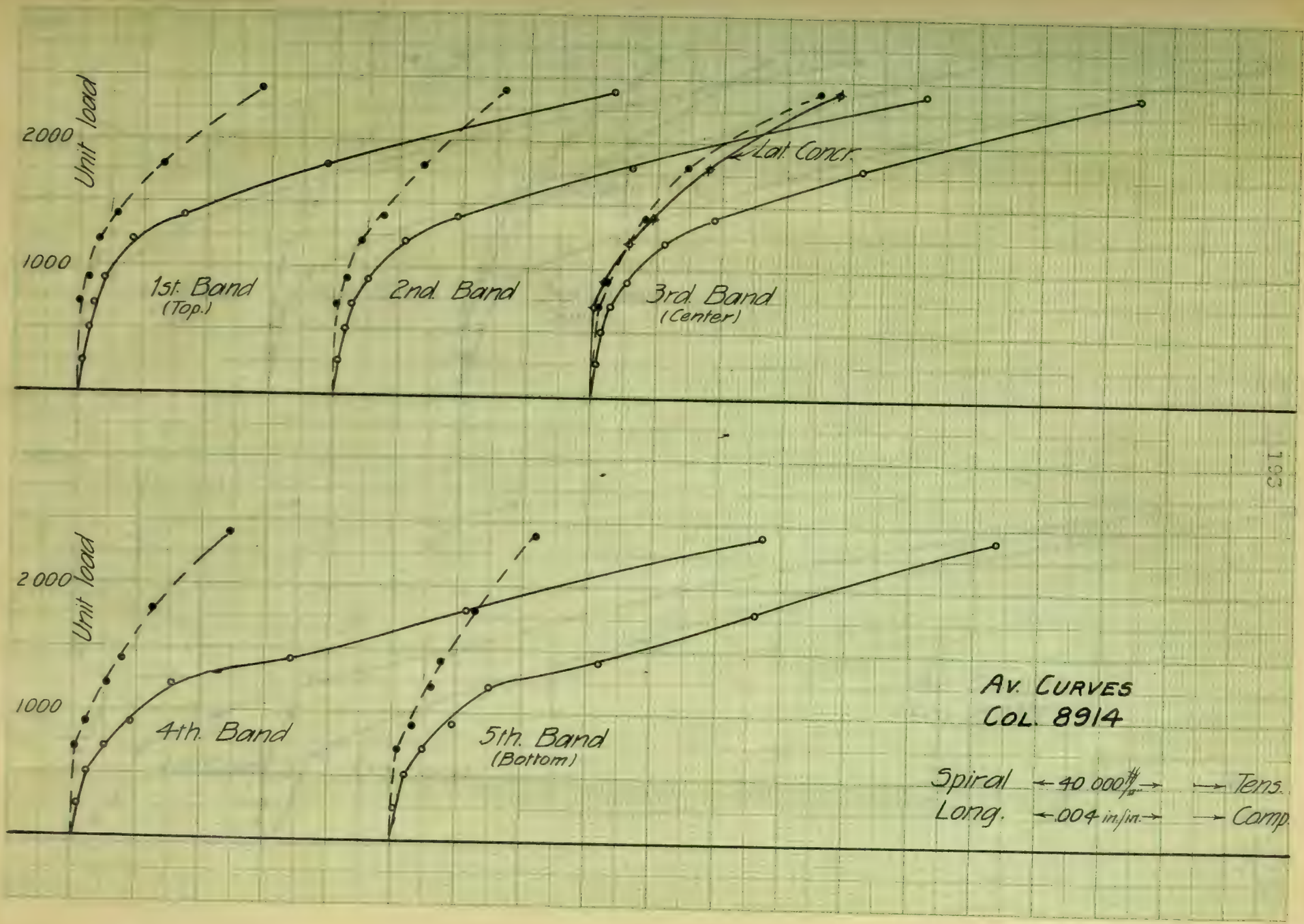

5000
4000
3000
2000
1000
Unit load
1st. Band
(Top)
2nd Band
3rd. Band
(Center)
4th. Band
5th. Band
(Bottom)
Av. Curves
Col. 8912
Spiral ← 40000 #/in² → → Tens.
Long. ← .004 in./in. → → Comp.





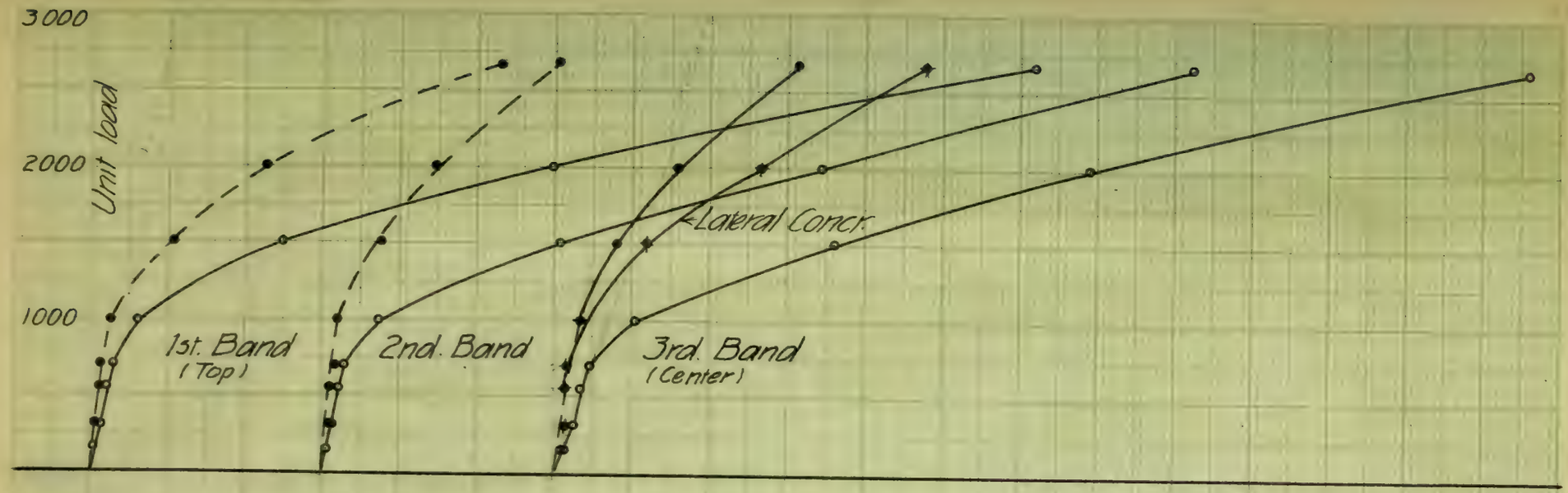
Av. Curves
Col. 8913
Spiral ←40 000 #/in.→ → Tens.
Long. ←.004 in./in.→ → Comp.

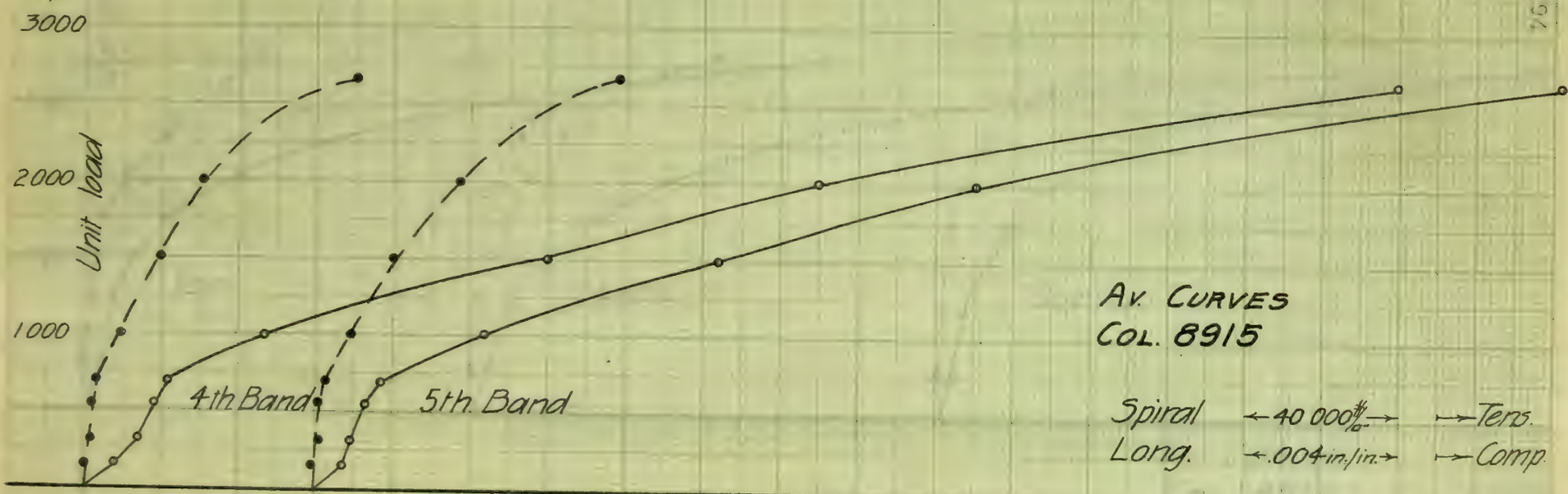



2000
Unit load
1000
1st. Band
(Top.)
2nd. Band
3rd. Band
(Center)
Lat. Concr.
2000
Unit load
1000
4th. Band
5th. Band
(Bottom)
Av. Curves
Col. 8914
Spiral ← 40 000 #/in. → → Tens.
Long. ← .004 in./in. → → Comp.







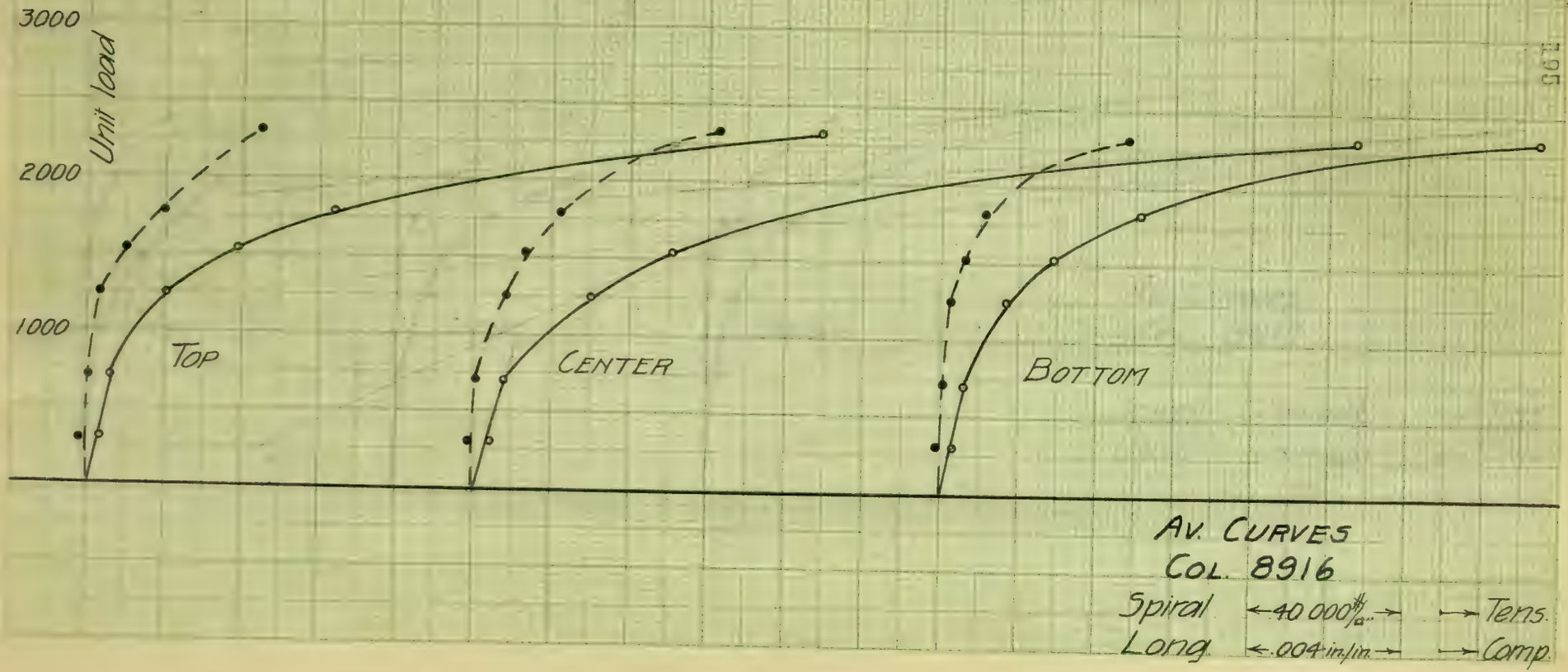


Av. Curves
Col. 8915

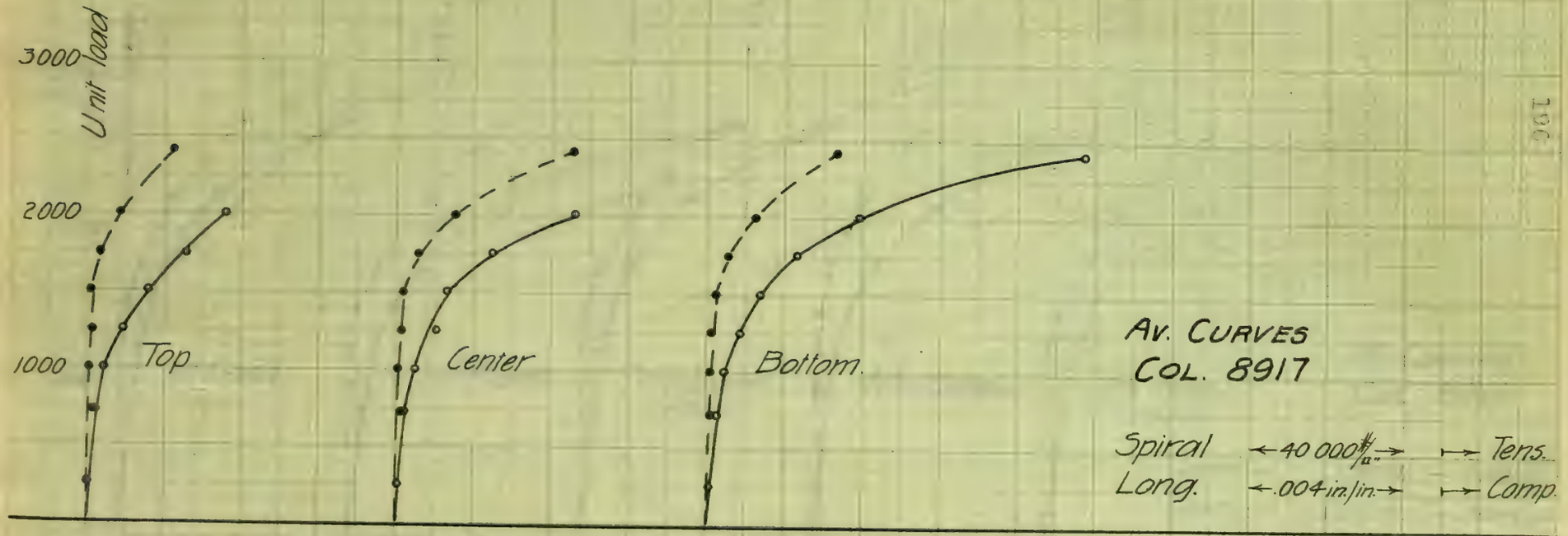
Spiral ←40 000#/□"→ ⟶Tens.
Long. ←.004 in./in.→ ⟶Comp.

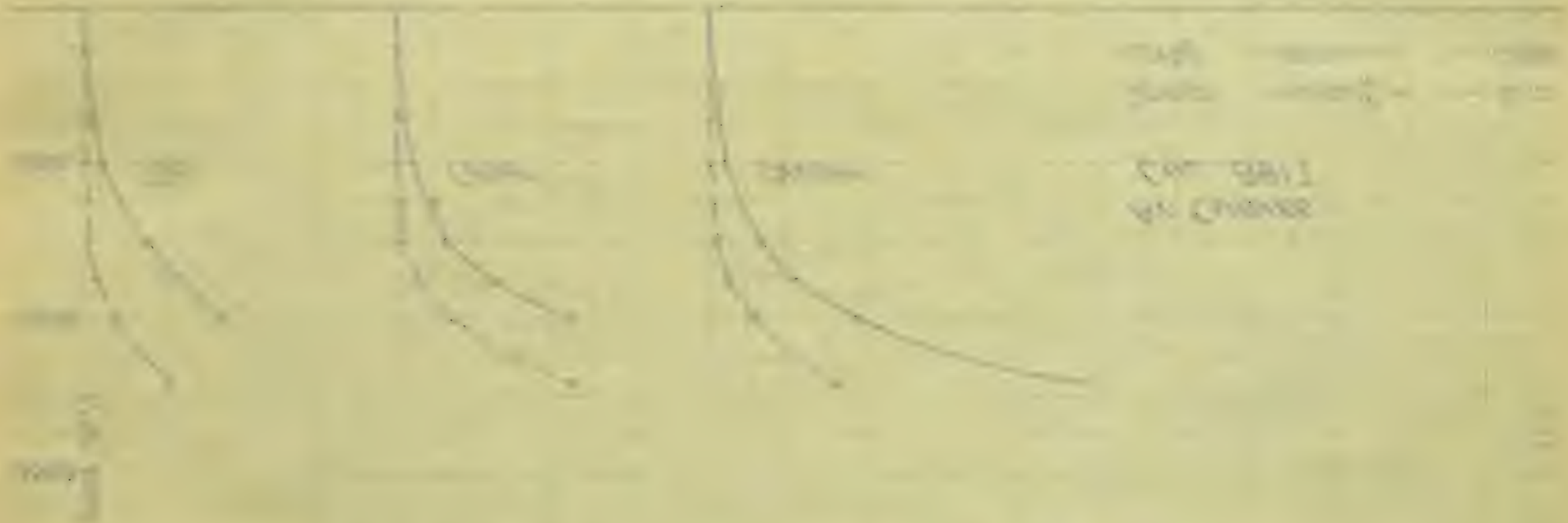
151

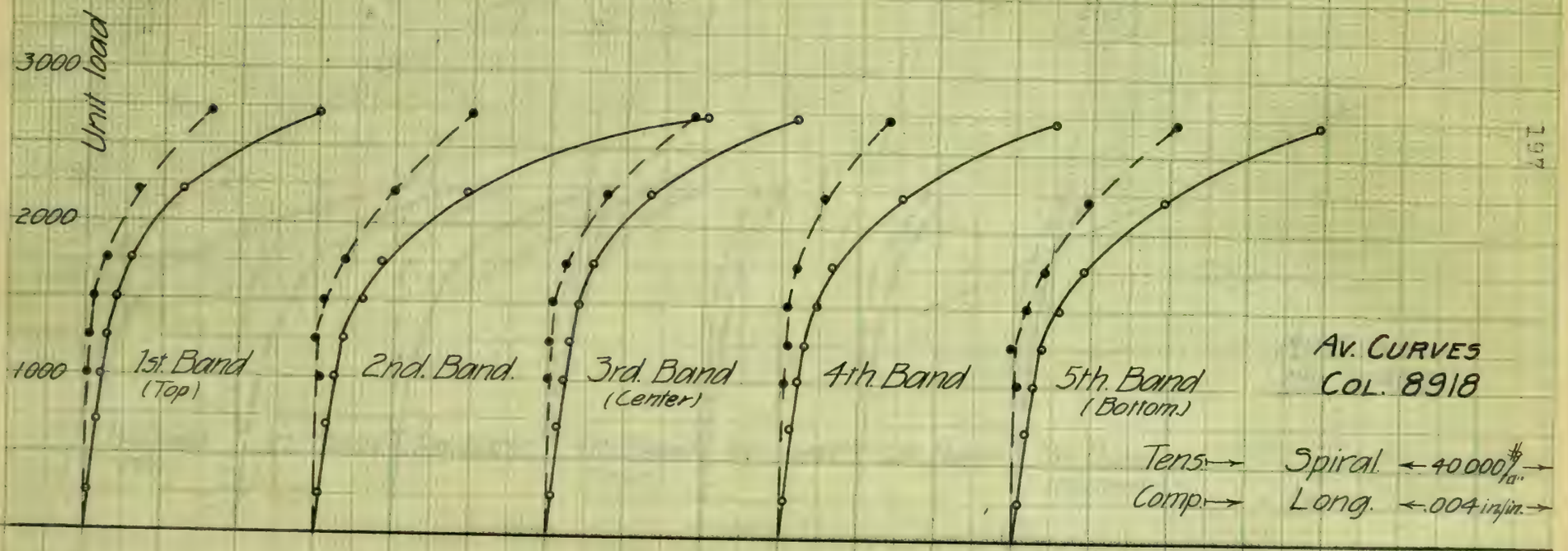



3000
2000
1000
Unit load
TOP
CENTER
BOTTOM
AV. CURVES
COL. 8916
Spiral ←40 000#/□"→ →Tens.
Long. ←.004 in/in→ →Comp.

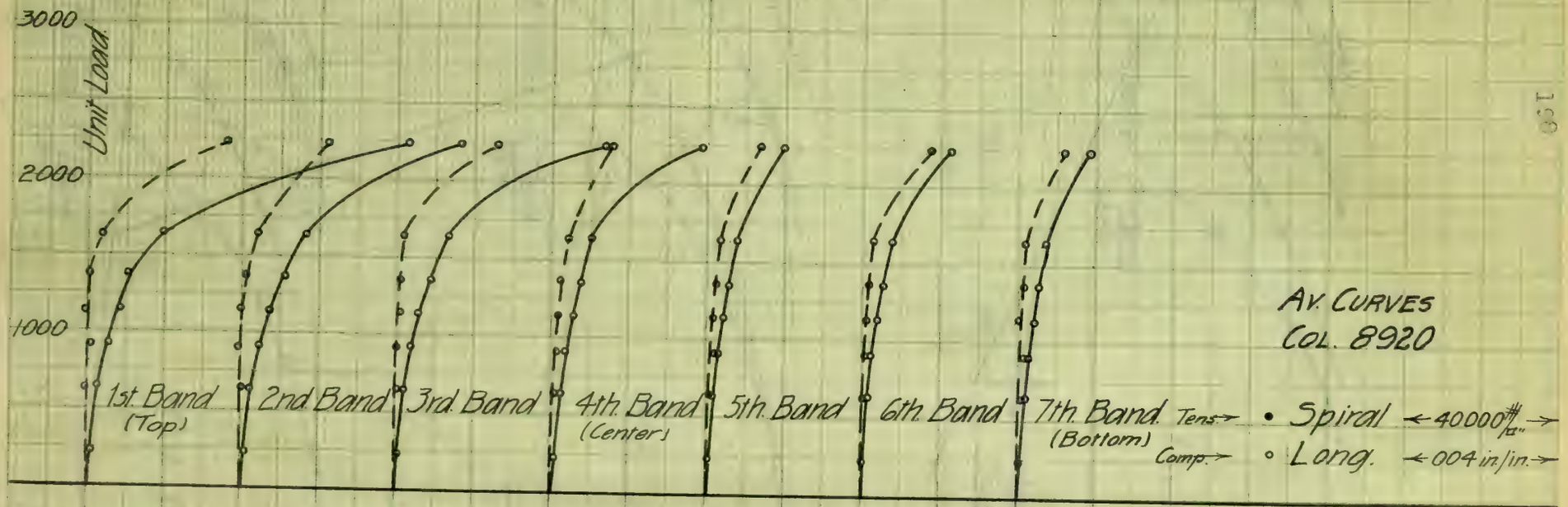



3000
Unit load
2000
1000
Top
Center
Bottom
Av. Curves
Col. 8917
Spiral ←40 000#/□"→ ⊢→ Tens.
Long. ←.004 in./in.→ ⊢→ Comp.

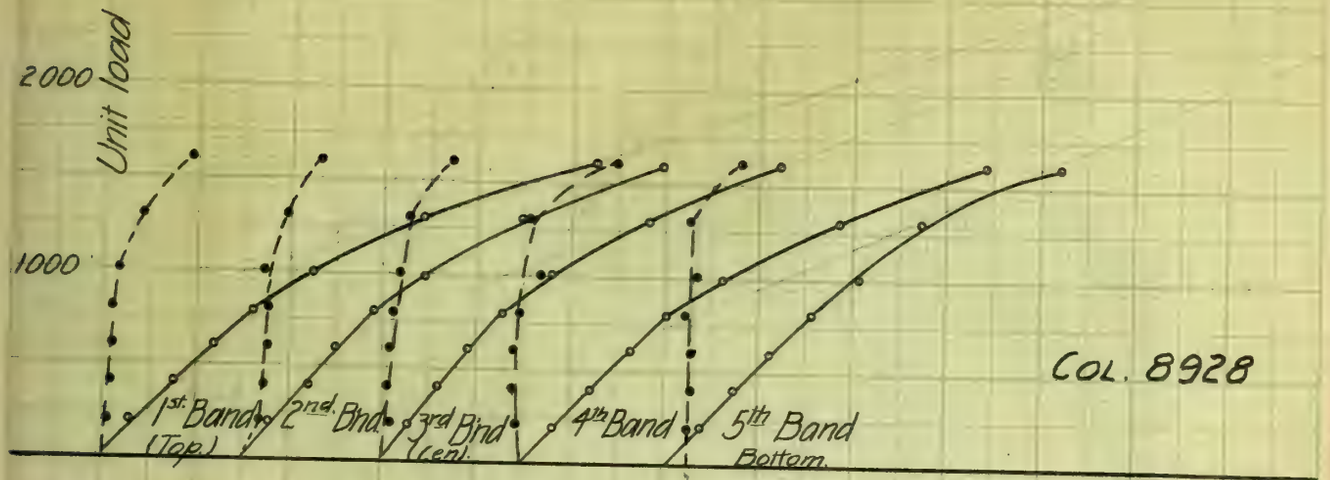



Unit load
3000
2000
1000
1st. Band
(Top)
2nd. Band.
3rd. Band
(Center)
4th. Band
5th. Band
(Bottom)
Av. Curves
Col. 8918
Tens. → Spiral. ← 40000 #/in²
Comp. → Long. ← .004 in/in.




3000
2000
1000
Unit Load
1st Band (Top)
2nd Band
3rd Band
4th Band (Center)
5th Band
6th Band
7th Band (Bottom)
Av. Curves
Col. 8920
Tens. → • Spiral ← 40000 #/□"
Comp. → ○ Long. ← 004 in/in →

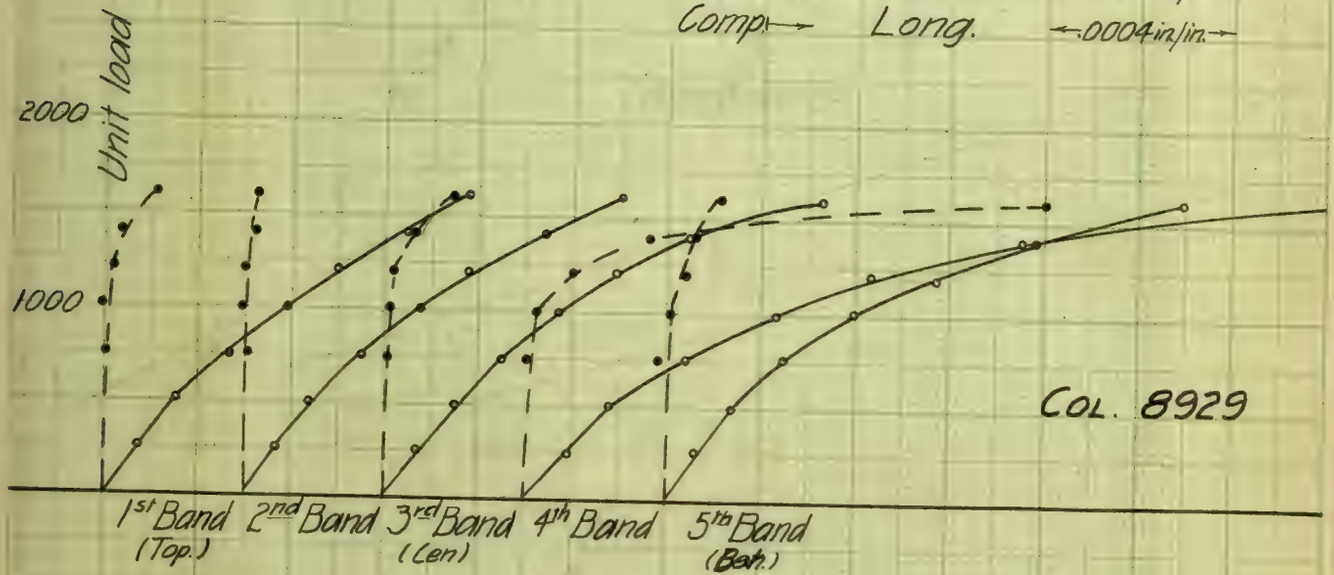


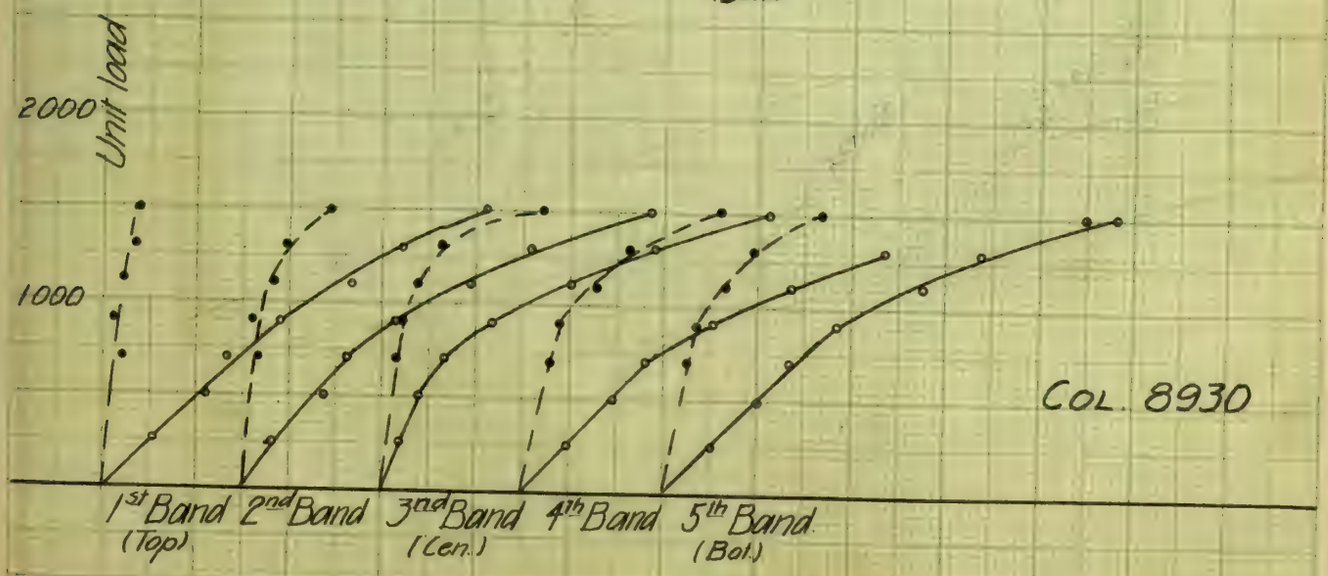


Av. Curves.

Tens. → Lateral ← .0004 in/in. →

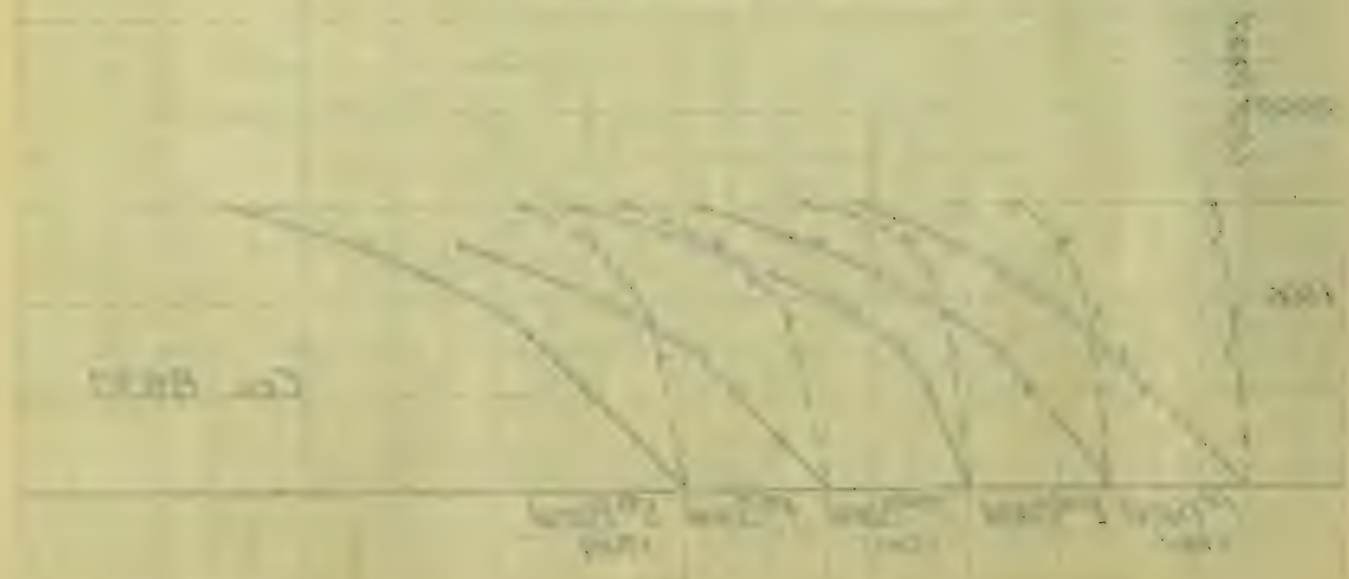
Comp. → Long. ← .0004 in/in. →











PHOTOGRAPHS



Plate 1. Column 2007, south side, north portion
[illegible] looking [illegible]

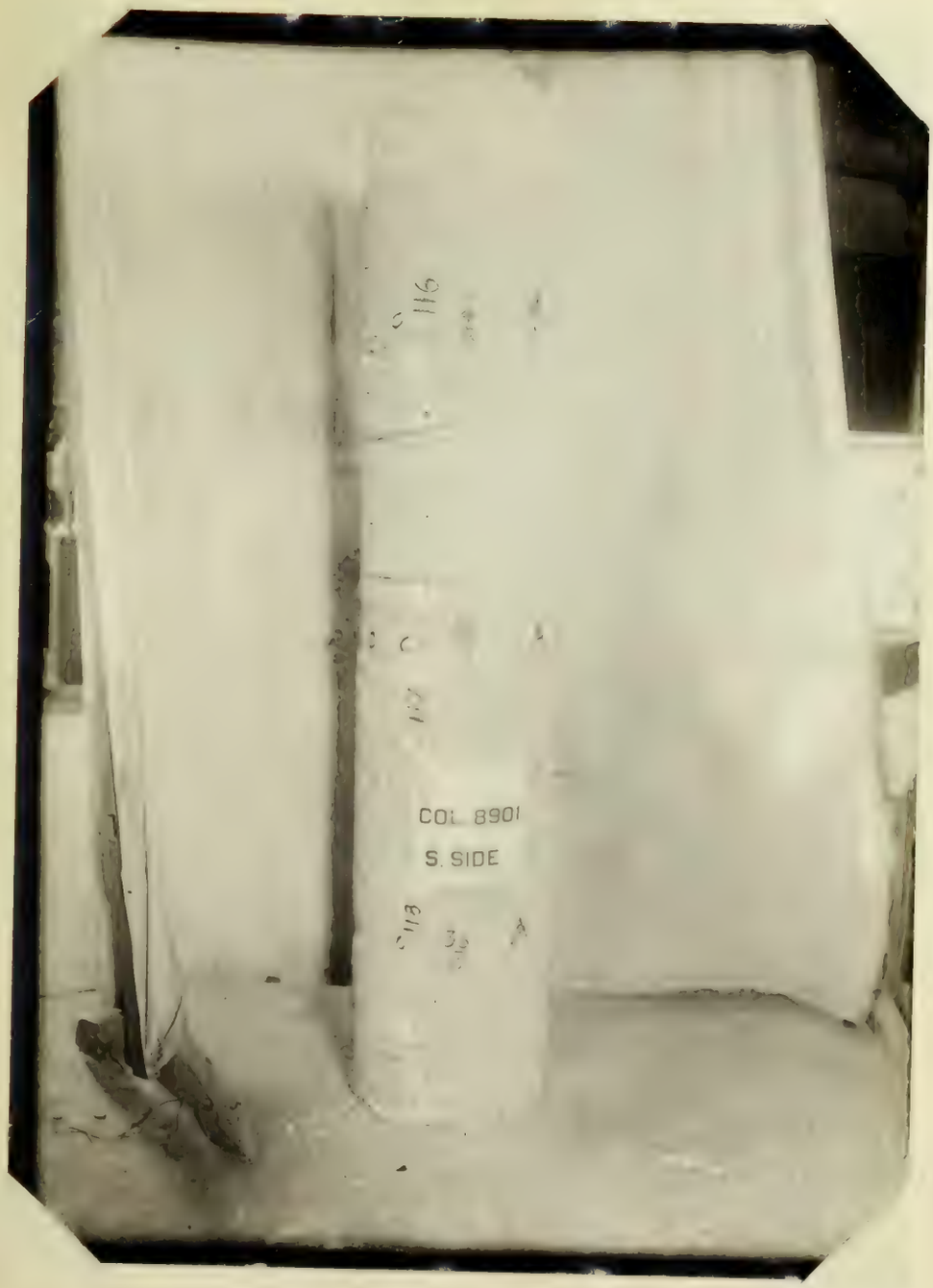


Fig. 1. Column 8901, south side, showing in
[illegible] in [illegible] of [illegible].



Fig. 5. Column 8901, north side, showing irregularity in pitch of spiral.



Fig. 1. Column [illegible], west side. Failure after loading. Cracking just started.



Fig. 5. Column 8F7, N. W. side, showing load at 421,000 lbs.



Fig. 6. Colman Cliff, north side, showing head [illegible] covering altitude level. Camera turned 90 degrees for photographing.

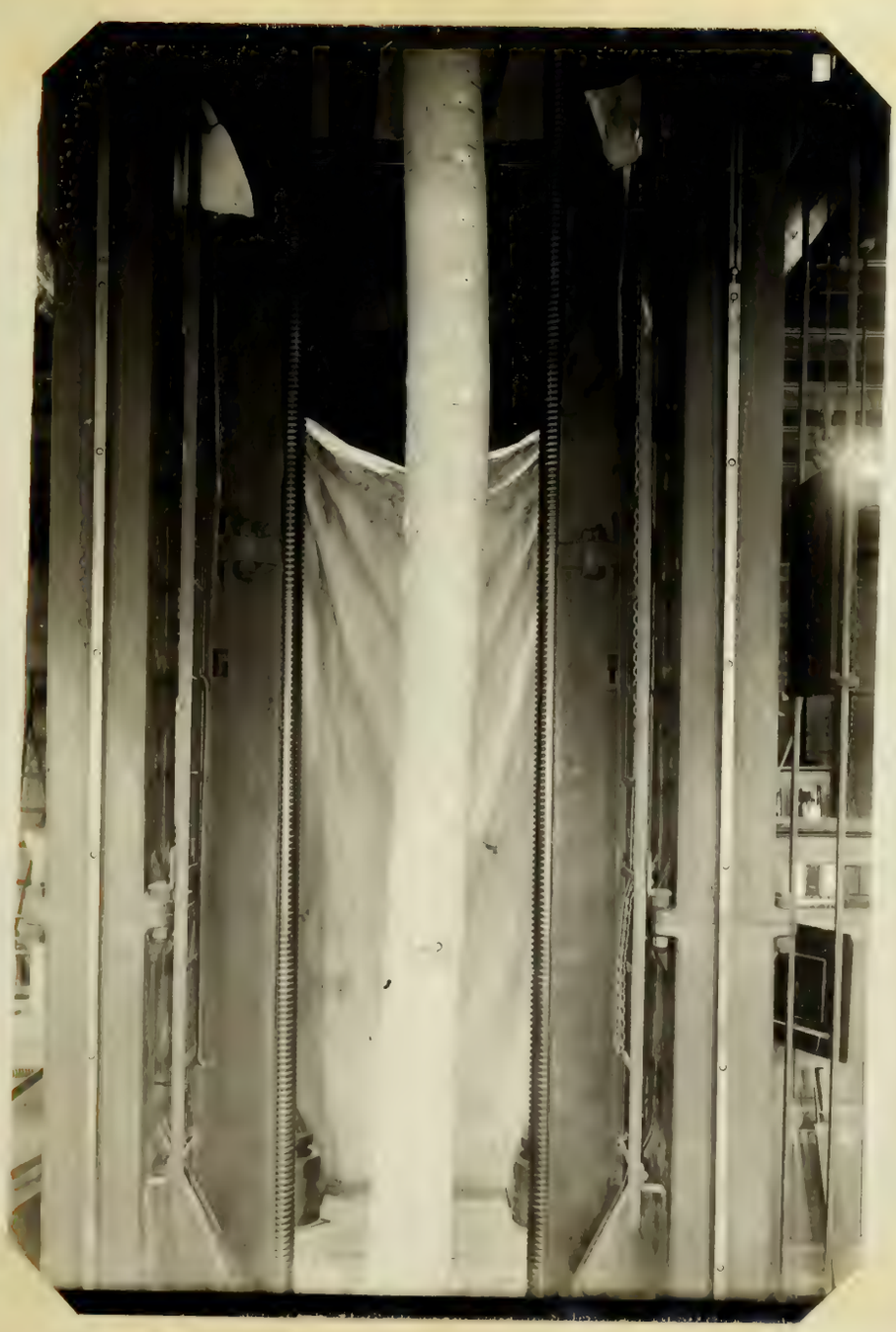


Fig. 7. [illegible]



Fig. 2. Column 8328, north side, showing cracking
of vertical bar. (Crack indicated)



Fig. 1. Prism 9282, west side, showing crushing at middle load.

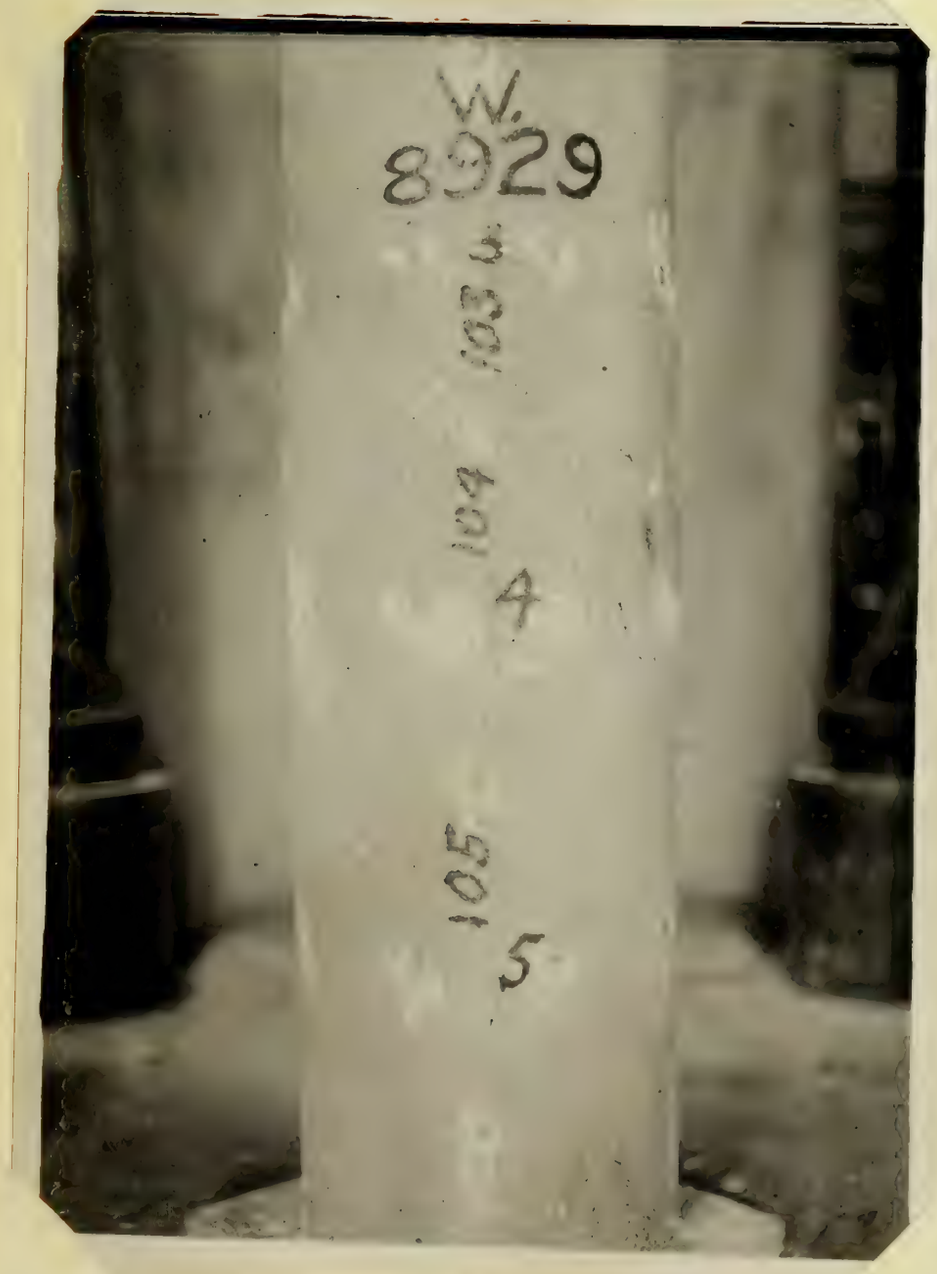


Fig. 10. Column 1787, west side, showing crumbling of elliptic load.



Fig. 17. [illegible], east side, showing [illegible]
[illegible].



Fig.12.-Showing method of anchoring end of spiral.

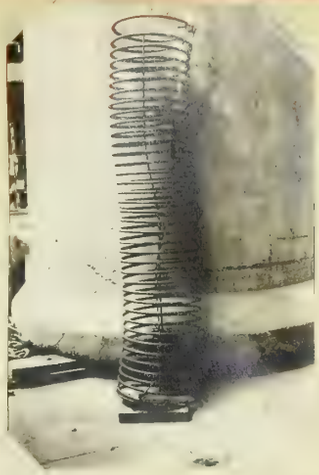


Fig.13.-Spiral for Col.8908, showing bend in spreader.



Fig.14.-Column 8901 in testing machine. Ready to remove rods.



Fig.15.-Col.8907 rodded up, ready to haul.



Fig.16.-Col. 8907 at ultimate load.

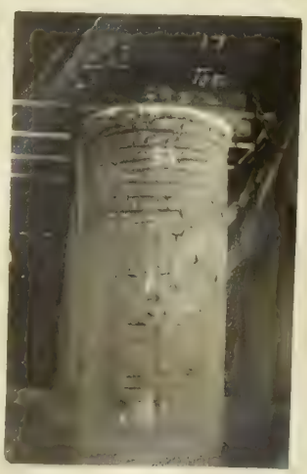


Fig.17.-Crushing at top of 8917 at ultimate load.

TABLES

TABLE II

Spiral Steel Tests

Nominal Diam.	Meas. Diam.	Area	Ult. Ld.	Ult. Stress	Elong. in 8 in.	Reduction in area
1/2"	.505	.200	17200	86000	20.5%	58.6%
"	.504	.199	16720	84100	22.1	49.2
"	.507	.202	16980	84100	22.7	59.3
"	.507	.202	16860	83500	21.2	59.0
"	.509	.203	17100	84200	19.6	52.7
"	.509	.203	17170	84600	20.5	61.5
Average:	.507	.201	17000	84400	21.1	56.7
5/16"	.320	.0804	7360	91600	20.0	61.0
"	.329	.0849	7345	86500	21.2	63.0
"	.323	.0818	7280	88300	22.9	62.5
"	.323	.0818	7140	87300	20.4	61.6
"	.328	.0843	7255	86000	19.3	55.0
"	.325	.0830	7280	87700	22.1	61.4
Average:	.324	.0827	7286	87870	21.0	60.7
3/16"	.189	.0280	2180	77900	0.9*	57.0
"	.190	.0284	2200	77600	3.25	60.0
"	.189	.0280	2230	79600	2.00	59.5
"	.189	.0280	2240	80000	2.00	59.5
"	.189	.0280	2190	78200	2.40	59.5
"	.189	.0280	2175	77700	2.00	59.5
Average:	.1891	.0281	2202	78500	2.11	59.1

*Omitted in average as it broke outside gaged length.

Proportion of Concrete by Weight.

TABLE III

Col. No.	Weight of Cement	Weight of Sand	Weight of Stone	Weight of Water	Mixture By Weight	Mixture By Vol.	% Water
8901	188 lb.	409 lb.	689 lb.	120 lb.	1-2.18-3.67	1-2-4	9.33%
8902	188	398	691	108	1-2.12-3.68	1-2-4	8.45
8903	188	385	665	108	1-2.05-3.54	1-2-4	8.72
8904		Same	as	8901			9.33
8905		Same	as	8902			
8906	188	398	665	114	1-2.13-3.54	1-2-4	9.13
8907	94	215	354	66	1-2.29-3.77	1-2-4	9.95
8908	188	400	673	108	1-2.13-3.57	1-2-4	8.57
8909		Same	as	8906			
8910	211	221	367	96	1-1.05-1.74	1-1-2	12.00
8911	188	195	344	72	1-1.04-1.83	1-1-2	9.63
8912	188	195	332	72	1-1.04-1.76	1-1-2	10.10
8913	78.3	248	406	60	1-3.16-5.18	1-3-6	8.80
8914	78.3	250	423	66	1-3.19-5.42	1-3-6	8.80
8915	70.5	221	375	57	1-3.14-5.33	1-3-6	8.57
8916	212	487	774	104	1-2.30-3.65	1-2-4	7.07
8917	188	398	668	108	1-2.12-3.56	1-2-4	8.62
8918	188	388	666	114	1-2.07-3.55	1-2-4	9.18
8919	331	751	1241	240	1-2.77-3.75	1-2-4	10.30
8920	376	742	1282	210	1-2.02-3.50	1-2-4	8.76
8921	376	811	1308	210	1-2.22-3.68	1-2-4	8.42
8922	353	731	1409	210	1-2.07-3.99	1-2-4	8.43
8923	353	746	1309	216	1-2.11-3.71	1-2-4	8.97
8924	376	780	1317	198	1-2.13-3.60	1-2-4	8.02
8925	353	742	1255	234	1-2.10-3.54	1-2-4	9.97
8926	376	754	1278	224	1-2.01-3.40	1-2-4	9.30
8927	376	786	1298	216	1-2.14-3.55	1-2-4	8.78
8928		Same	as	8908			
8929		Same	as	8903			
8930	94	194	323	66	1-2.07-3.44	1-2-4	108%

TABLE IV

Stress in Spiral 5000 lb. per sq. in.

Col. No.	Top Unit Load	Top Long. Def.	Center Unit Load	Center Long. Def.	Bottom Unit Load	Bottom Long. Def.	Average Unit Load	Average Long. Def.	Val. of $\frac{1}{\mu}$
8901	1350	.0015	1750	.0016	1800	.0026			
2	2000	.0027	1700	.0019	1700	.0021			
3	2000	.0016	1700	.0013	1750	.0017			
Ave.	1780	.0019	1716	.0016	1750	.0021	1749	.0019	11.4
8904	1450	.0016	1650	.0016	1500	.0017			
5	1750	.0014	1700	.0017	1880	.0021			
6	1750	.0013	1450	.0014	2000	.0018			
Ave.	1650	.0014	1600	.0016	1790	.0019	1680	.0016	9.6
8907	1950	.0026	1550	.0036	1650	.0023			
8	1700	.0010	1400	.0009	2000	.0018			
9	2000	.0012	1750	.0014	2200	.0024			
Ave.	1880	.0016	1570	.0020	1950	.0021	1800	.0019	11.4
8910	2000	.0012	2200	.0013	2870	.0018			
11	2500	.0011	2380	.0009	3000	.0016			
12	2500	.0011	2750	.0012	3000	.0012			
Ave.	2330	.0011	2440	.0011	2960	.0015	2580	.0012	7.2
8913	1600	.0034	1300	.0028	1330	.0024			
14	1120	.0014	900	.0012	830	.0015			
15	1000	.0012	850	.0014	800	.0026			
Ave.	1240	.0020	1020	.0018	220	.0022	1060	.0023	13.8
8916	1320	.0023	1050	.0021	1450	.0025			
17	1850	.0029	1750	.0025	1750	.0023			
18	1750	.0012	1750	.0012	1850	.0017			
Ave.	1640	.0021	1520	.0019	1680	.0022	1610	.0021	12.6

Stress in Spiral 10,000 lb. per sq. in.

8901	1450	.0020	1900	.0022	1860	.0029			
2	2070	.0030	1730	.0020	1830	.0020			
3	2200	.0020	1780	.0014	1870	.0023			
Ave.	1910	.0023	1800	.0019	1857	.0024	1856	.0022	6.6
8904	1080	.0026	1900	.0025	1750	.0025			
5	2000	.0018	1920	.0026	2030	.0029			
6	1970	.0018	1700	.0021	2250	.0026			
Ave.	1980	.0021	1840	.0024	2010	.0027	1910	.0024	7.2
8907	2300	.0036	1920	.0051	2000	.0037			
8	2150	.0021	1870	.0020	2300	.0030			
9	2500	.0022	2000	.0021	2500	.0034			
Ave.	2320	.0027	1930	.0031	2270	.0034	2170	.0031	9.3
8910	2300	.0018	2500	.0020	3100	.0023			
11	3100	.0018	3050	.0016	3450	.0016			
12	3100	.0018	3250	.0017	3350	.0021			
Ave.	2830	.0018	2930	.0018	3300	.0020	3020	.0019	5.7
8913	1770	.0048	1520	.0040	1450	.0043			
14	1350	.0028	1150	.0021	1220	.0028			
15	1200	.0025	1250	.0046	1050	.0044			
Ave.	1440	.0034	1310	.0036	1220	.0038	1320	.0036	10.8
8916	1850	.0039	1380	.0037	1750	.0045			
17	2050	.0039	1900	.0035	1920	.0035			
18	2000	.0019	2000	.0019	1900	.0022			
Ave.	1870	.0033	1760	.0030	1960	.0034	1830	.0032	9.6

TABLE IV (Cont.)

Stress in Spiral 20,000 lb. per sq. in.

Col. No.	Top Unit Load	Top Long. Def.	Center Unit Load	Center Long. Def.	Bottom Unit Load	Bottom Long. Def.	Average Unit Load	Average Long. Def.	Val. of $\frac{1}{\mu}$
8901:	2180	.0031:			2000	.0029:			
2:	2230	.0038:	1900	.0027:	2000	.0030:			
3:	2430	.0027:	2000	.0023:	2050	.0032:			
Ave.:	2250	.0032:	1950	.0025:	2016	.0030:	2087	.0029:	4.3
8904:	2000	.0048:	2220	.0041:	2120	.0045:			
5:	2250	.0023:	2320	.0042:	2050	.0040:			
6:	2350	.0030:	2050	.0035:	2650	.0045:			
Ave.:	2200	.0034:	2200	.0039:	2270	.0043:	2220	.0039:	5.8
8907:	2800		2330		2450				
8:	2720	.0044:	2450	.0048:	2870	.0072:			
9:	3100	.0050:	2500	.0044:	3100	.0060:			
Ave.:	2870	.0047:	2430	.0046:	2810	.0069:	2700	.0054:	8.1
8910:	2780	.0029:	3000	.0032:	3650	.0044:			
11:	3600	.0028:	3520	.0024:	3400	.0025:			
12:	3600	.0028:	3900	.0024:	3800	.0028:			
Ave.:	3300	.0028:	3470	.0028:	3620	.0032:	3470	.0029:	4.4
8913:	2020	.0066:	1820	.0064:	1800	.0080:			
14:	1630	.0060:	1550	.0056:	1550	.0080:			
15:	1450	.0046:	1630	.0088:	1450	.0098:			
Ave.:	1700	.0057:	1670	.0069:	1600	.0086:	1660	.0071:	10.6
8916:	1870	.0070:	1800	.0073:	1720	.0083:			
17:	2350		2100		2130				
18:	2450	.0039:	2320	.0033:	2270	.0043:			
Ave.:	2210	.0054:	2070	.0053:	2040	.0063:	2110	.0057:	8.5

Stress in Spiral 30,000 lb. per sq. in.

8901:	1750	.0041:							
2:	2350	.0049:	2100	.0039:	2120	.0036:			
3:	2680	.0033:	2100	.0030:	2800	.0040:			
Ave.:	2350	.0041:	2100	.0034:	2160	.0038:	2180	.0038:	3.8
8904:	2270	.0070:	2500	.0056:	2430	.0071:			
5:	2500	.0035:	2530	.0058:	2570	.0060:			
6:	2570	.0043:	2870	.0056:	2870	.0067:			
Ave.:	2440	.0047:	2630	.0057:	2620	.0066:	2560	.0057:	5.7
8907:	3130		2650		2800				
8:	3150	.0076:	2870	.0078:	3250	.0095:			
9:	3530	.0082:	2950	.0078:	3500	.0092:			
Ave.:	3270	.0079:	2820	.0078:	3180	.0093:	3090	.0083:	8.3
8910:	3100	.0043:	3330	.0044:					
11:	3870	.0037:	3770	.0032:	4280	.0033:			
12:	3950	.0035:	4200	.0042:	4120	.0039:			
Ave.:	3640	.0038:	3770	.0039:	4200	.0036:	3830	.0038:	3.8
8913:	2270	.0094:	2100	.0096:	2130	.0118:			
14:	1880	.0090:	1800	.0083:	2000	.2126:			
15:	1680	.0068:	1950	.0126:	1770	.0140:			
Ave.:	1940	.0084:	1950	.0101:	1930	.0128:	1940	.0104:	10.4
8916:	2080	.0110:	1950	.0105:	2100	.0107:			
17:			2250		2350	.0088:			
18:	2670	.0057:	2550	.0048:	2720	.0060:			
Ave.:	2370	.0083:	2250	.0076:	2390	.0085:	2330	.0082:	8.2

TABLE IV (Cont.)

Stress in Spiral 40,000 lb. per sq. in.

Col. No.	Top Unit Load	Top Long. Def.	Center Unit Load	Center Long. Def.	Bottom Unit Load	Bottom Long. Def.	Average Unit Load	Average Long. Def.	Val. of $\frac{1}{\mu}$
8901:	1850	.0051:							
2:	2450	.0060:	2250	.0050:	2300	.0047:			
3:	2950	.0047:	2200	.0036:	2350	.0050:			
Ave.:	2416	.0053:	2220	.0043:	2320	.0048:	2336	.0049:	3.7
8904:	2500	.0091:	2680	.0060:	2700	.0096:			
5:	2700	.0049:	2700	.0072:	2850	.0084:			
6:	2800	.0060:	2580	.0082:	3100	.0095:			
Ave.:	2670	.0067:	2650	.0073:	2880	.0092:	2730	.0077:	5.8
8907:	3400		2950		3150				
8:	3500	.0108:	3150	.0130:	3500	.0108:			
9:	3550	.0108:	3250	.0106:	3750	.0114:			
Ave.:	3480	.0108:	3120	.0118:	3430	.0111:	3340	0112	8.3
8910:	3350	.0056:	3550	.0058:					
11:	4100	.0046:	3950	.0037:					
12:	4220	.0044:	4350	.0054:	4370	.0054:			
Ave.:	3890	.0047:	3950	.0050:	4370	.0054:	3980	.0049:	3.8
8913:	2500	.0120:	2280	.0125:	2350	.0143:			
14:	2080	.0120:	2000	.0114:	2300	.0174:			
15:	2900	.0103:	2170	.0170:	2050	.0180:			
Ave.:	2490	.0114:	2150	.0136:	2230	.0166:	2290	.0139:	10.4
8916:	2200	.0153:	2070	.0108:	2380	.0138:			
17:			2370						
18:					2386	.0077:			
Ave.:	2200	.0153:	2200	.0108:	2480	.0107:	2310	.0119:	8.9

Stress in Spiral 50,000 lb. per sq. in.

8901:	1930	.0059:							
2:	2550	.0072:	2350	.0058:	2430	.0058:			
3:	3070	.0045:	2330	.0044:	2550	.0058:			
Ave.:	2516	.0059:	2340	.0052:	2490	.0058:	2460	.0056:	3.4
8904:	2730	.0116:	2800	.0075:	2850	.0113:			
5:	2880	.0070:	2900	.0092:	3050	.0104:			
6:	2930	.0071:	2700	.0095:	3320	.0112:			
Ave.:	2850	.0086:	2800	.0087:	3070	.0110:	2910	.0094:	5.7
8907:	3670		3200		3450				
8:	3700	.0124:	3450	.0170:	3750	.0130:			
9:	3970	.0122:	3520	.0068:	4000	.0142:			
Ave.:	3780	.0123:	3390	.0119:	3730	.0136:	3600	.0126:	7.5
8910:	3420	.0064:							
11:	4300	.0054:	4370	.0060:					
12:	4350	.0047:	4480	.0065:	4530	.0073:			
Ave.:	4020	.0055:	4420	.0062:	4530	.0073:	4340	.0060:	3.6
8913:	2750	.0158:	2450	.0147:	2500	.0169:			
14:	2300	.0149:	2150	.0136:					
15:	2070	.0128:	2450	.0204:	2350	.0245:			
Ave.:	2370	.0145:	2330	.0162:	2420	.0207:	2370	.0176:	10.5
8916:			2200	.0137:	2320	.0154:			
17:									
18:									
Ave.:			2200	.0137:	2320	.0154:	2260	.0145:	8.7

TABLE V

Ave. Moduli of Elasticity

No.	Moduli at Top	Moduli at Center	Moduli at Bottom	Average Ec	Ave. for Cyl. Ec'	Ratio $\frac{Ec}{Ec'}$
8901	2,670,000	1,820,000	2,500,000			
2	1,880,000	1,950,000	2,000,000			
3	2,310,000	2,430,000	2,470,000			
Ave.	2,290,000	2,070,000	2,320,000	2,230,000	3,600,000	0.62
4	1,960,000	1,940,000	1,550,000			
5	2,300,000	2,250,000	2,140,000			
6	2,250,000	1,770,000	2,150,000			
Ave.	2,170,000	1,990,000	1,960,000	2,040,000	3,480,000	.59
7	1,110,000*	560,000*	1,200,000*			
8	2,500,000	2,140,000	2,500,000			
9	2,820,000	2,500,000	2,500,000			
Ave.	2,660,000	2,320,000	2,500,000	2,490,000	3,130,000	.80
10	2,580,000	2,500,000	4,200,000			
11	3,630,000	3,630,000	3,700,000			
12	2,860,000	3,150,000	3,330,000			
Ave.	3,020,000	3,090,000	3,740,000	3,280,000	4,110,000	.80
13	2,140,000	2,500,000	4,200,000			
14	1,660,000	1,700,000	1,360,000			
15	1,180,000*	700,000*	400,000*			
Ave.	1,900,000	2,100,000	1,330,000	1,770,000	3,240,000	.55
16	1,030,000*	1,070,000*	1,120,000*			
17	2,400,000	2,070,000	2,140,000			
18	2,000,000	2,000,000	2,280,000			
Ave.	2,200,000	2,030,000	2,180,000	2,140,000	3,680,000	.58
20	2,140,000	2,500,000	3,330,000			
21						
Ave.						
22						
23						
24						
Ave.						
25						
26						
27						
Ave.						
28	2,440,000	3,180,000	2,560,000			
29	3,280,000	3,000,000	3,390,000			
30	2,420,000	6,600,000*	2,530,000			
Ave.	2,710,000	3,090,000	2,830,000	2,880,000	3,180,000	.91

*Omit in Average

Column No.	Le	Ult. Load on Columns	Unit Ld. at Ult. on Column.	Unit Load at Scaling	Ratio to Cyl. Str.	Column No.
8901		250 000*	2340*	1750*	1.09	8901
8902		316 000	2920	2200	1.03	8902
8903		308 000	2850	2100	1.08	8903
Av.						Av.
8904		312 000	~~2880~~	2150		
8905		464 000*	4220*	1900*	1.18	8904
8906		502 000	4450	2170	1.01	8905
Av.		491 000	4350	1900	1.03	8906
8907		496 000	4400	2035		Av.
8908		603 000°	5340°	1600*	1.31	8907
8909		600 000°	5310°	1800	0.91	8908
Av.		600 000°	5260°	2100	1.14	8909
8910		601 000°	5300°	1950		Av
8911		500 700*	4430*	2800*	1.16	8910
8912		590 000	5000	3500	1.06	8911
Av.		584 000	5160	3700	1.02	8912
8913		587 000	5080	3600		Av.
8914		464 000	4100	1400	1.21	8913
8915		414 000	3600	1200	1.30	8914
Av.		422 000	3740	1060	1.90	8915
8916	10	433 000	3810	1220		Av.
8917	10	266 000*	2380*	1260*	0.91	8916
8918	10	265 500	2410	1750	1.06	8917
Av.		350 000	3100	2500	1.16	8918
8920†	19ft-	308 000	2750	2120		Av.
8921†	19ft-8	276 000	2220	1940	0.67	8920
Av.		252 000	1990	1780	0.86	8921
8922	19ft-8	264 000	2100	1860		Av.
8923	19ft-8	192 000	1560	1460	0.66	8922
8924†	19ft-8	180 000	1350	1130	0.76	8923
Av.		222 000	1670	1370	0.58	8924
•8925	19ft-8	198 000	1530	1320		Av.
•8926†	19ft-8	264 000*	1400ft*	1340†*	0.71	8925
•8927†	19ft-8	346 000	1900†	1800†	0.73	8926
Av.	5'	314 000	1690†	1500†	0.59	8927
8928	19ft-8	330 000	1795	1650		Av.
8929	19ft-8	235 000	1900			8928
8930	19ft-8	203 000	1690			8929
Av.		222 000	1670			8930
		220 000	1750			Av.

† Made

• Reinforc

culating these

TABLE VI.

Column No.	Length ft	Mix.	Spiral Diam. Core (in.)	Spiral Area Core (sq.in.)	Spiral Diam (in.)	Spiral Area (sq.in.)	Spiral Percent	Date Made mo. da. yr.	Date Tested mo. da. yr.	Age, Days	Auxiliary Specimens Cubes Age	Cubes Unit Ld.	Cylinders Age	Cylinders Unit Ld.	E_c	Ult. Load on Columns	Unit Ld. at Ult. on Column.	Unit Load at Scaling	Ratio to Cyl Str.	Column No.
8901	5	1-2-4	11 1/16	107	0.188	0.0276	0.94	11-21-13	1-27-14	67	60	1907 *	64	1604 *	3 640 000 *	250 000 *	2340 *	1750 *	1.09	8901
8902	5	do	11 3/4	108	0.187	.0274	93	12-16-13	2-19-14	65	74	2580	74	2140	3 750 000	316 000	2920	2200	1.03	8902
8903	5	do	11 3/4	108	0.177	.0245	.83	12-27-13	2-25-14	60	58	2780	58	2080	3 450 000	308 000	2850	2100	1.08	8903
Av.							0.90			64	64	2680	65	2110	3 600 000	312 000	~~2880~~	2150		Av.
8904	5	1-2-4	11 1/8	110	0.323	0.0817	2.75	11 21-13	1-24-14	64	64	1907 *	64	1604 *	3 640 000 *	464 000 *	4220 *	1900 *	1.18	8904
8905	5	do.	12	113	.324	.0823	2.73	12-16-13	2-18-14	64	74	2580	74	2140	3 750 000	502 000	4450	2170	1.01	8905
8906	5	do.	12	113	.324	0823	2.73	12-27-13	2-27-14	62	63	2460	74	1840	3 080 000	491 000	4350	1900	1.03	8906
Av.							2.74			63	67	2520	71	1990	3 410 000	496 000	4400	2035		Av.
8907	5	1-2-4	12	113	0.509	0.203	4.51	11-1-13	12-31-13	60	66	1456 *	67	1220 *	2 670 000 *	603 000 °	5340 °	1600 *	1.31	8907
8908	5	do.	12	113	.500	.196	4.35	12-16-13	2-20-14	66	69	2840	69	1987	3 160 000	600 000 °	5310 °	1800	0.91	8908
8909	5	do.	12 1/16	114	.495	.192	4.25	12-27-13	2-25-14	60	63	2460	74	1840	3 080 000	600 000 °	5260 °	2100	1.14	8909
Av.							4.37			62	66	2650	70	1915	3 120 000	601 000 °	5300 °	1950		Av
8910	5	1-1-2	12	113	0.314	0.0773	2.57	11-25-13	2-5-14	72	66	2890 *	66	2420 *	3 640 000 *	500 700 *	4430 *	2800 *	1.16	8910
8911	5	do.	12 1/4	118	.322	.0814	2.66	12-26-13	2-23-14	59	59	4800	59	3302	4 770 000	590 000	5000	3500	1.06	8911
8912	5	do.	12	113	.324	.0823	2.74	12-30-13	3-4-14	62	67	3820	60	3620	3 920 000	584 000	5160	3700	1.02	8912
Av.							2.66			64	64	4310	62	3460	4 340 000	587 000	5080	3600		Av.
8913	5	1-3-6	12	113	0.320	0.0803	2.67	11-25-13	2-11-14	78	66	1395	66	1155	3 850 000	464 000	4100	1400	1.21	8913
8914	5	do.	12	113	.324	.0823	2.75	12-27-13	3-2-14	65	63	1520	63	924	2 630 000	414 000	3600	1200	1.30	8914
8915	5	do.	12	113	.324	.0823	2.75	12-30-13	3-5-14	65	60	1195	60	560	1 480 000	422 000	3740	1060	1.90	8915
Av.							2.72			69	62	1370	~~63~~	880	2 650 000	433 000	3810	1220		Av.
8916	10	1-2-4	11 15/16	112	0.319	0.0797	2.67	10-31-13	1-5-14	66	67	1790 *	67	1390 *	1 900 000 *	266 000 *	2380 *	1260 *	0.91	8916
8917	10	do.	11 7/8	110	.320	.0803	2.75	11-22-13	2-2-13	72	69	2060	69	1650	4 170 000	265 500	2410	1750	1.06	8917
8918	10	do.	12	113	.320	.0803	2.69	12-29-13	3-3-14	64	61	2630	61	2160	3 200 000	350 000	3100	2500	1.16	8918
Av.							2.70			67	66	2340	66	1900	3 680 000	308 000	2750	2120		Av.
8920 †	19ft-8in	1-2-4	12	124 ◎	.324	0.0823	2.74	1-20-14	3-24-14	63	62	3130	62	2890	3 570 000	276 000	2220	1940	0.67	8920
8921 †	19ft-8in.	do.		127 ◎	.324	.0823	2.74	2-10-14	4-13-14	62	59	2690	59	2080	3 510 000	252 000	1990	1780	0.86	8921
Av.							2.74			62	60	2410	60	2480	3 540 000	264 000	2100	1860		Av.
8922	19ft-8in	1-2-4	12	123 ◎	0.507	0.202	4.48	11-3-13	1-12-14	70	64	1736	65	1690	2 350 000	192 000	1560	1460	0.66	8922
8923	19ft-8in	do.	12 1/2	133 ◎	.507	202	4.30	11-15-13	1-21-14	67	68	2010	68	1480	2 460 000	180 000	1350	1130	0.76	8923
8924 †	19ft-8in	do.	12 1/2	133 ◎	.507	.202	4.30	1-30-14	4-4-14	64	63	2970	63	2345	2 780 000	222 000	1670	1370	0.58	8924
Av.							4.36			67	65	2240	65	1870	2 530 000	198 000	1530	1320		Av.
• 8925	19ft-8in.	1-2-4	12 3/4	133 ◎	0.495	0.192	4.17	12-4-13	2-13-14	71	76	2620 *	76	1895 *	3 920 000 *	264 000 *	1400 *	1340 *	0.71	8925
• 8926 †	19ft-8in.	do.	12	127 ◎	.507	202	4.48	1-14-14	3-19-14	64	68	2990	68	2450	3 300 000	346 000	1900 †	1800 †	0.73	8926
• 8927 †	19ft-8in.	do.		131 ◎	.507	.202	4.35	2-17-14	4-21-14	63	62	2740	62	2570	3 650 000	314 000	1690 †	1500 †	0.59	8927
Av.							4.33			66	69	2865	69	2510	3 470 000	330 000	1795	1650		Av.
8928	19ft-8in	1-2-4	12 5/8	124	NONE			12-16-13	2-23-14	69	69	2840	69	1987	3 160 000	235 000	1900			8928
8929	19ft-8in	do.	12 3/8	120				12-27-13	2-26-14	61	58	2780	58	2080	3 450 000	203 000	1690			8929
8930	19ft-8in	do.	13	133				12-30-13	3-4-14	64	60	1860	60	1720	2 900 000	222 000	1670			8930
Av.										65	62	2490	62	1930	3 170 000	220 000	1750			Av.

† Made with new form

• Reinforced with 5 1-in round Long. bars.

◎ Gross area.

* Omit in average

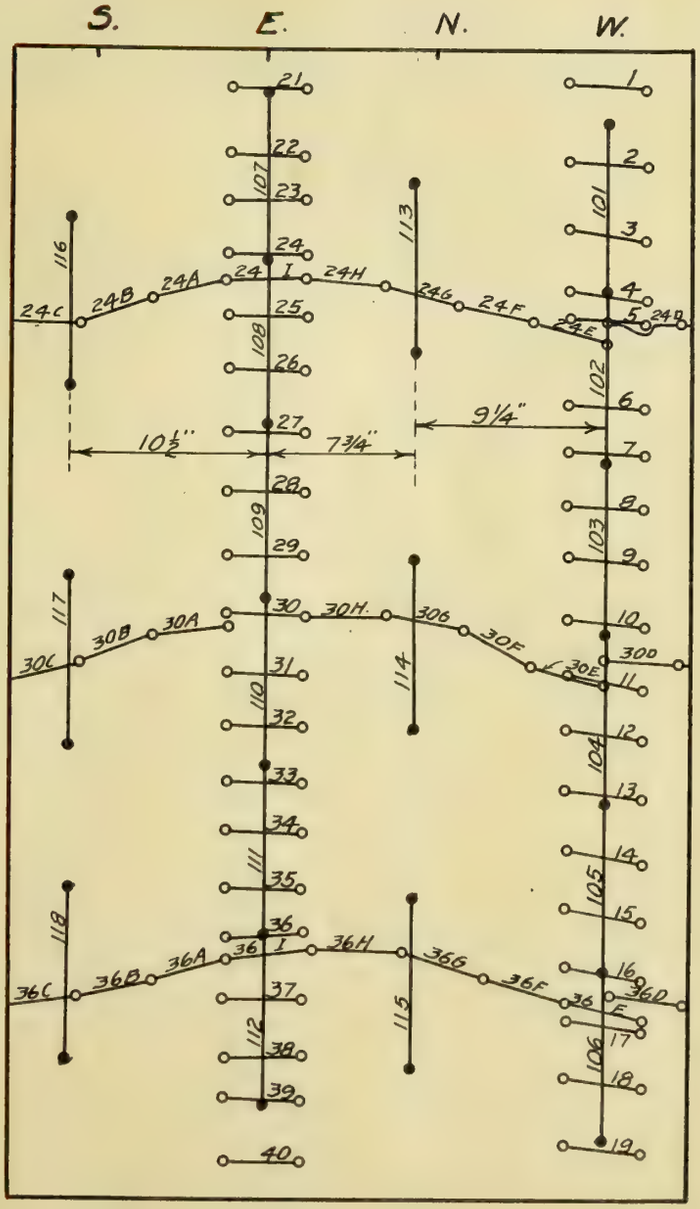
° Not an ultimate load.

† ☐ assumed as 15 in calculating these

DRAWINGS

COL. 8901

Length 61 1/8"



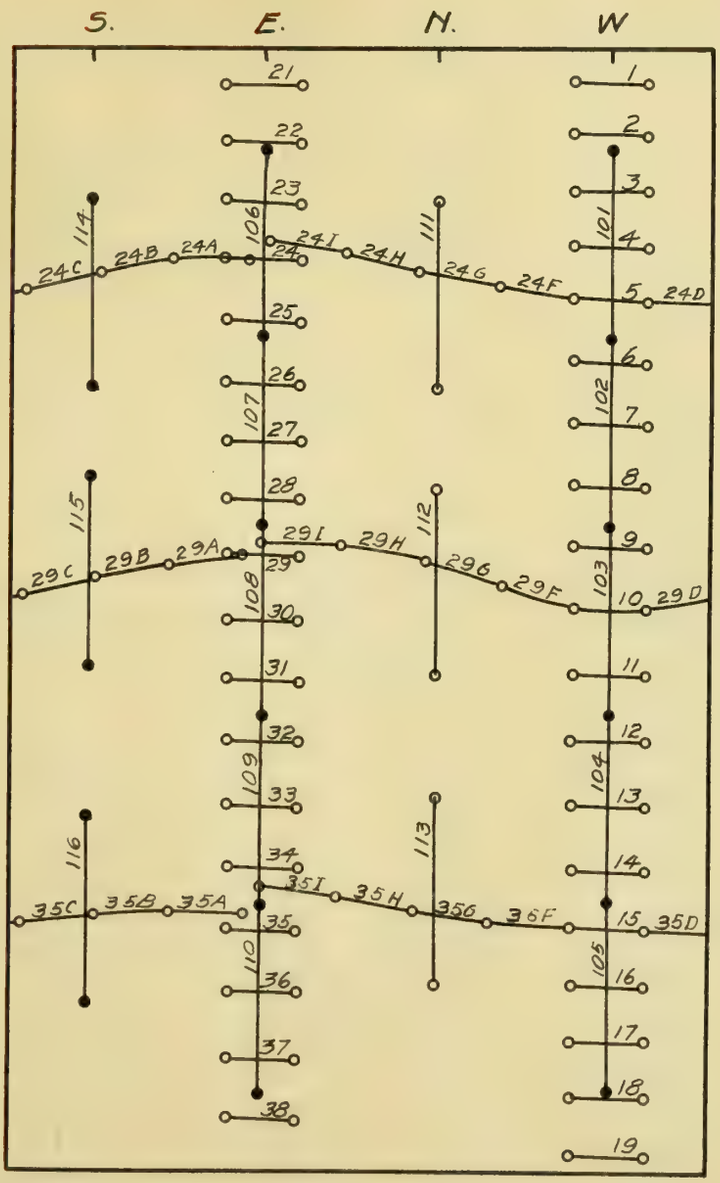
• Gage lines on concrete 9"

○ Gage lines on steel 4"

Scale: 1"=10"

COL. 8902

Length $59\frac{7}{8}$"



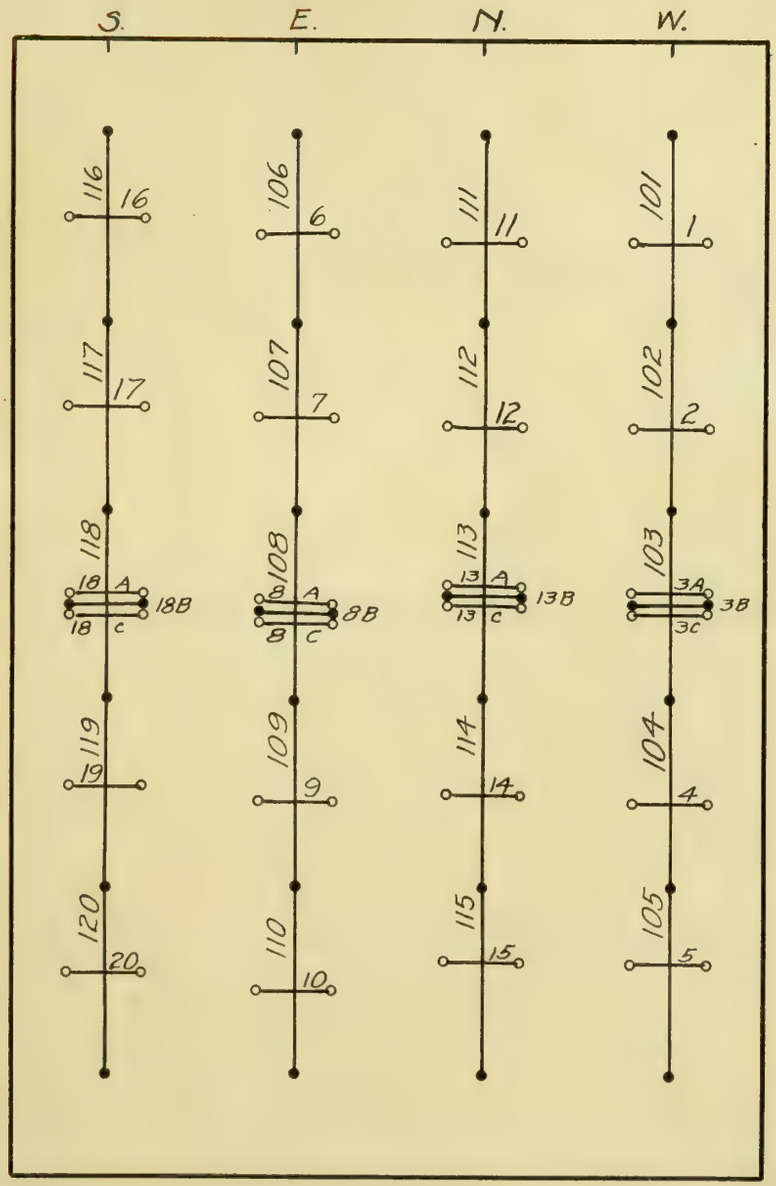
• Gage lines on concrete 10"

◦ Gage lines on steel 4"

Scale: 1"=10"

COL. 8903

Length 60 3/8"

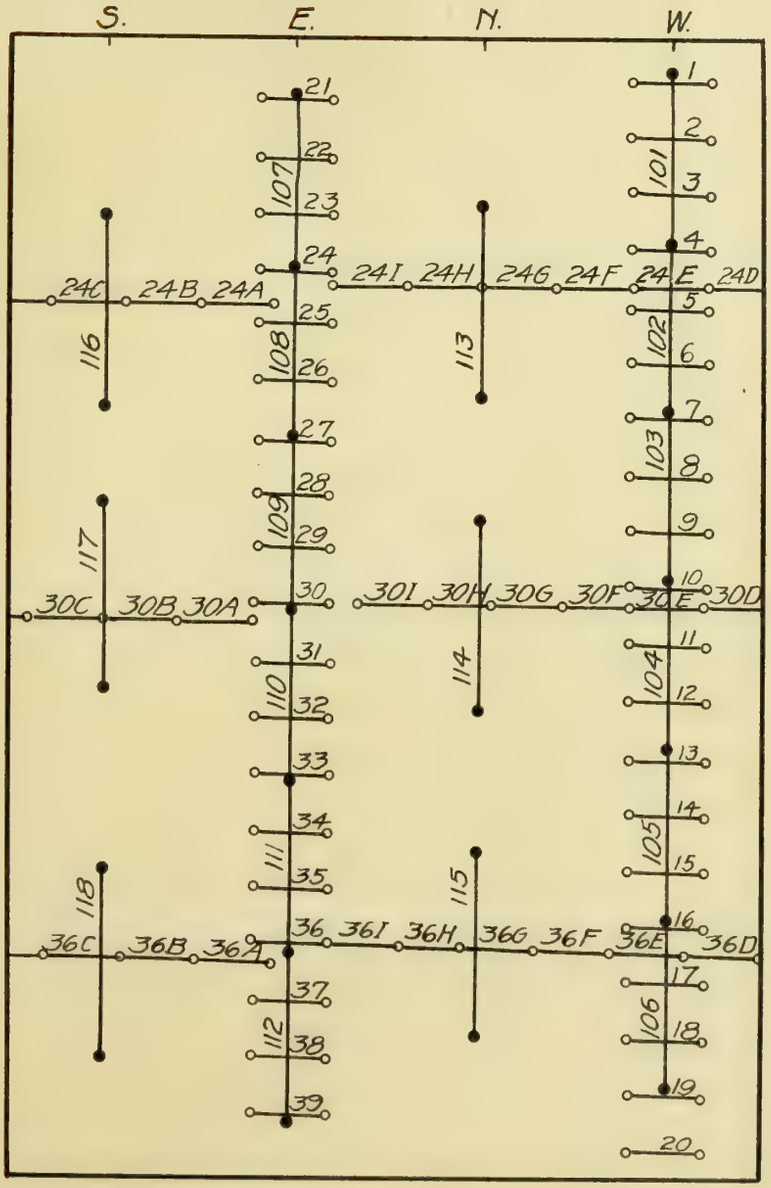


- Gage lines on concrete 10" & 4
- Gage lines on steel 4"

Scale: 1" = 10"

COL. 8904

Length



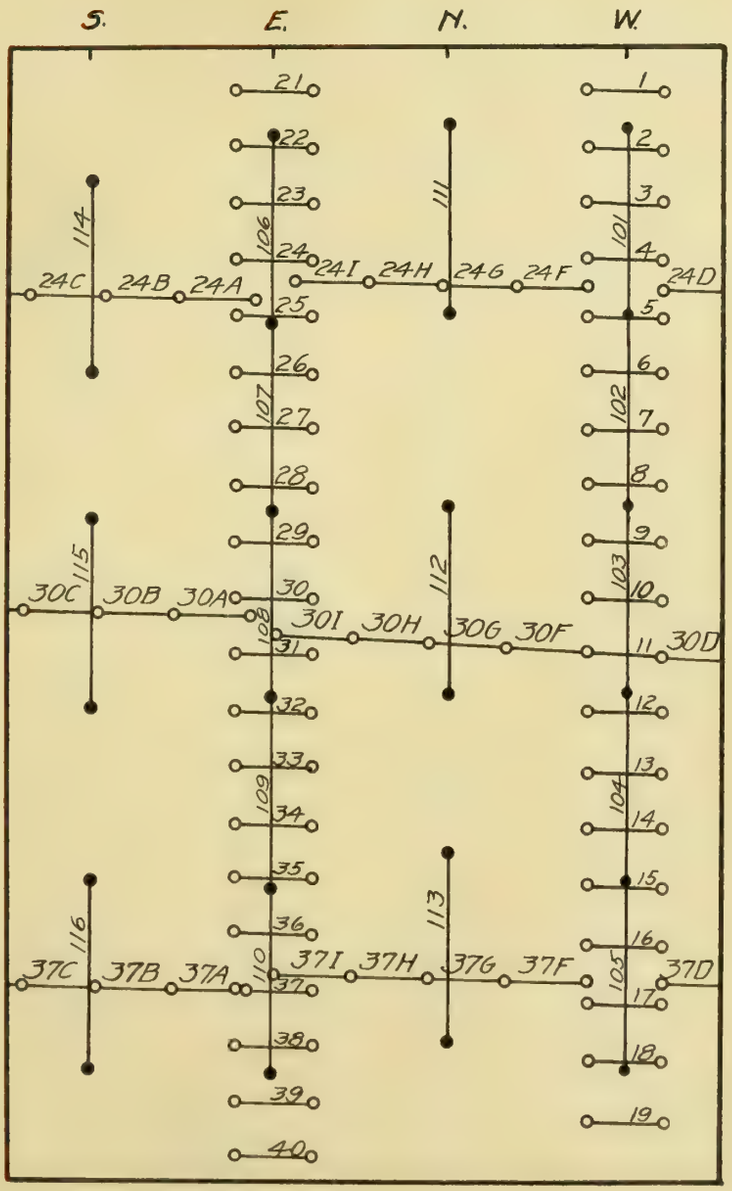
• Gage lines on concrete 9"

◦ Gage lines on steel 4"

Scale: 1" = 10"

COL. 8905

Length 60¼"



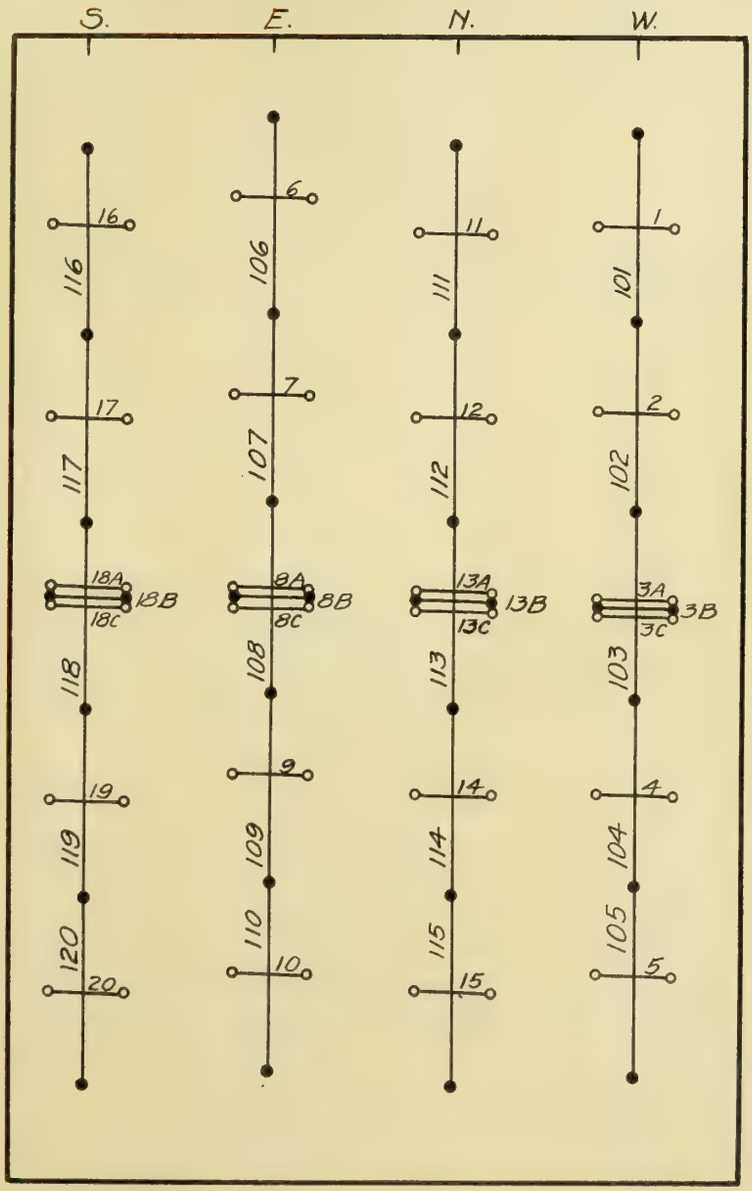
• Gage lines on concrete 10"

○ Gage lines on steel 4"

Scale: 1"=10"

COL. 8906

Length 60 3/4"

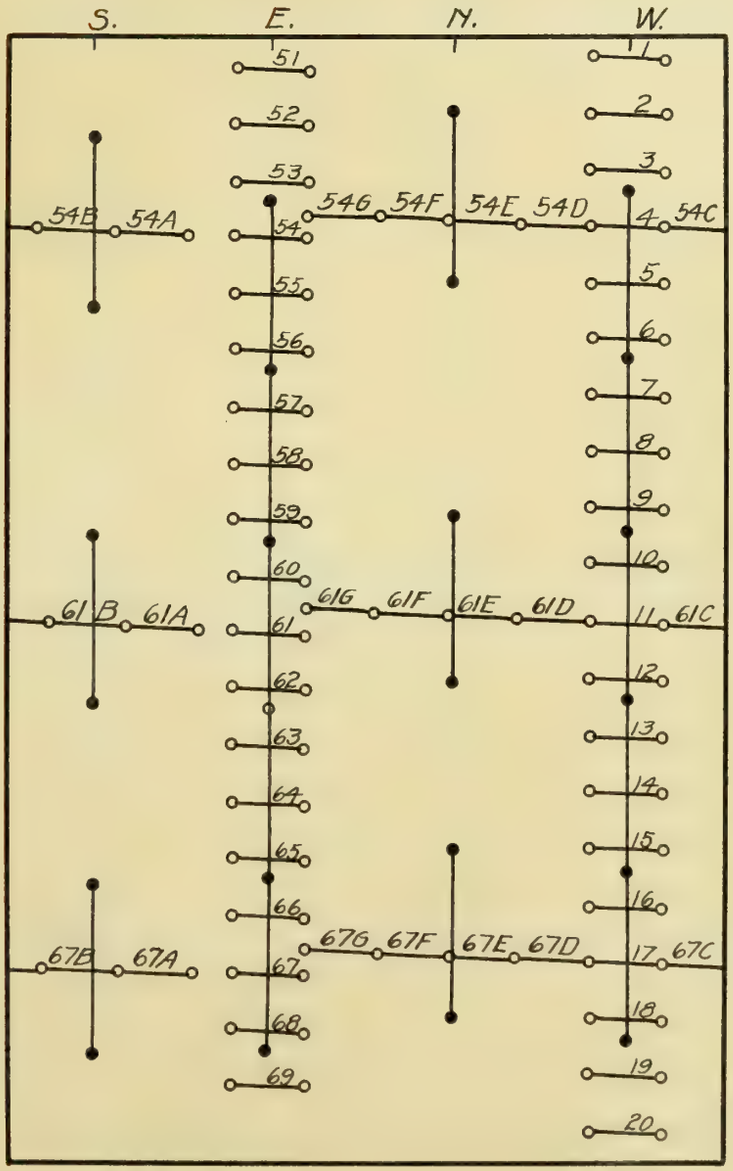


- Gage lines on concrete 10" & 4"
- Gage lines on steel 4"

Scale: 1"=10"

COL. 8907

Length



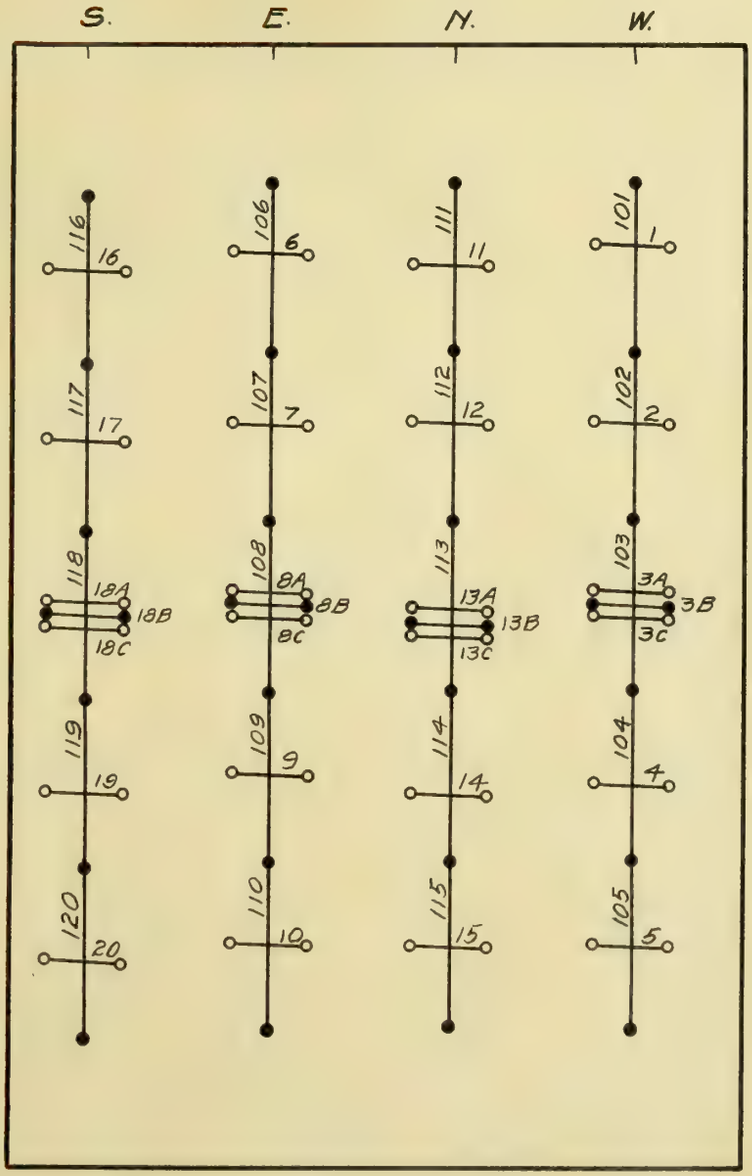
• Gage lines on concrete 9"

° Gage lines on steel 4"

Scale: 1" = 10"

COL. 8908

Length 60"



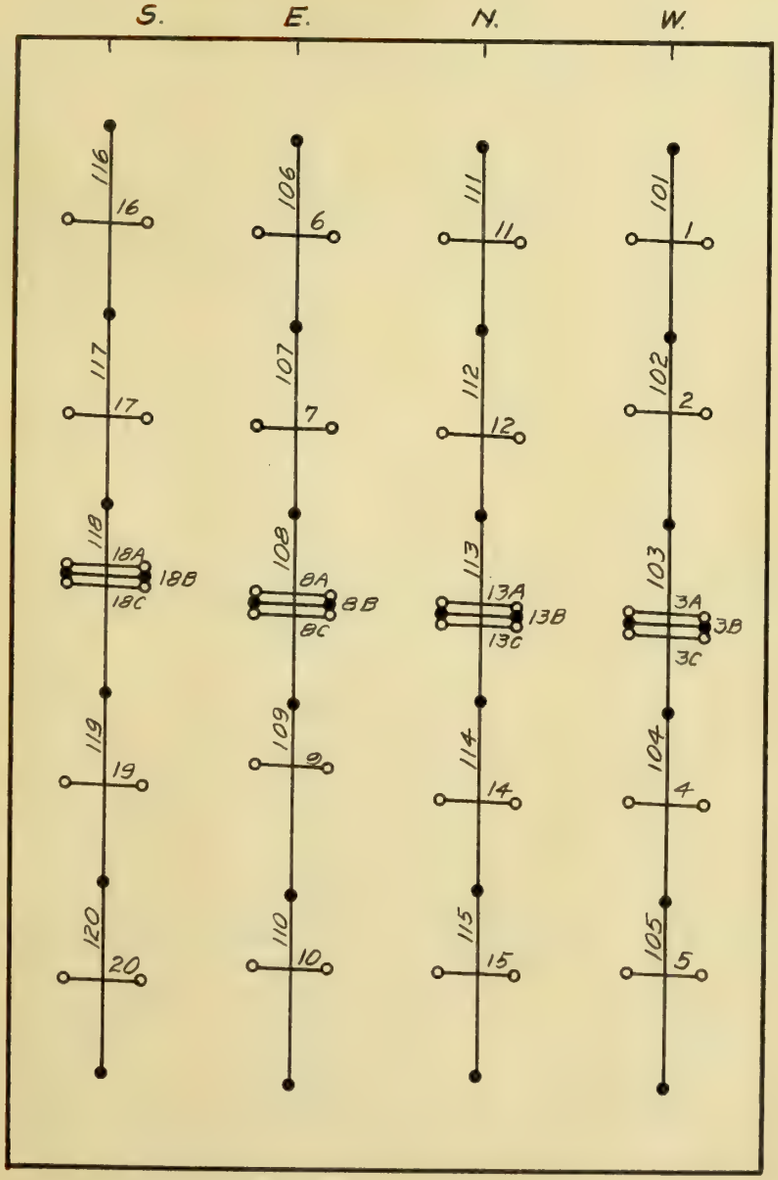
• Gage lines on concrete 9" & 4"

° Gage lines on steel 4"

Scale 1" = 10"

COL. 8909

Length 60"

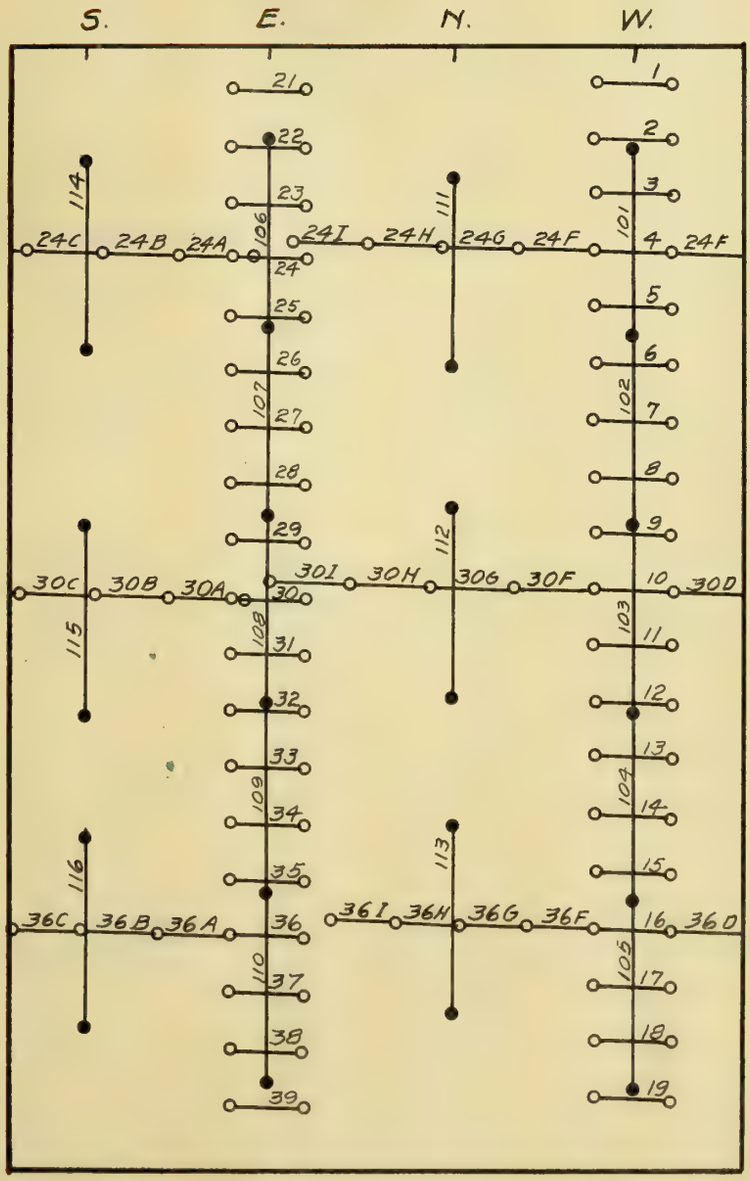


- Gage line on concrete 10" & 4"
- Gage lines on steel 4"

Scale 1"=10"

COL. 8910

Length 60"

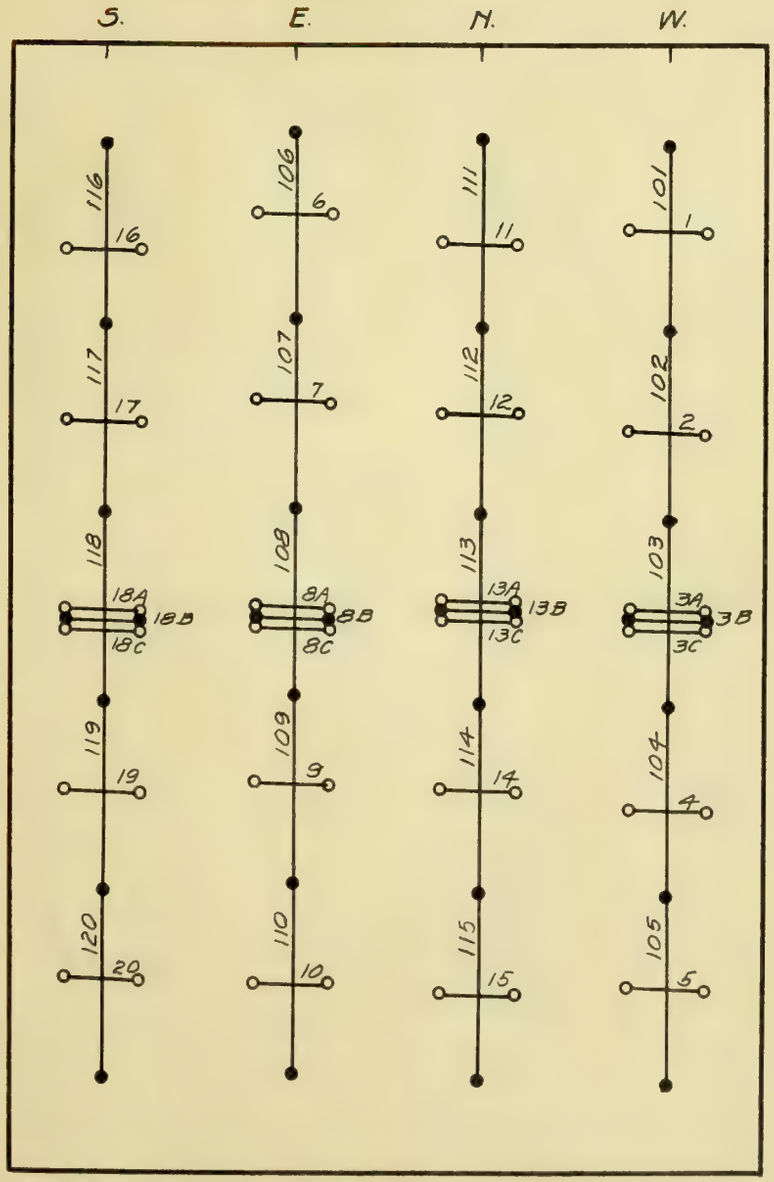


• Gage lines on concrete 10"

▫ Gage lines on steel 4"

COL. 8911

Length $60\frac{1}{8}$"

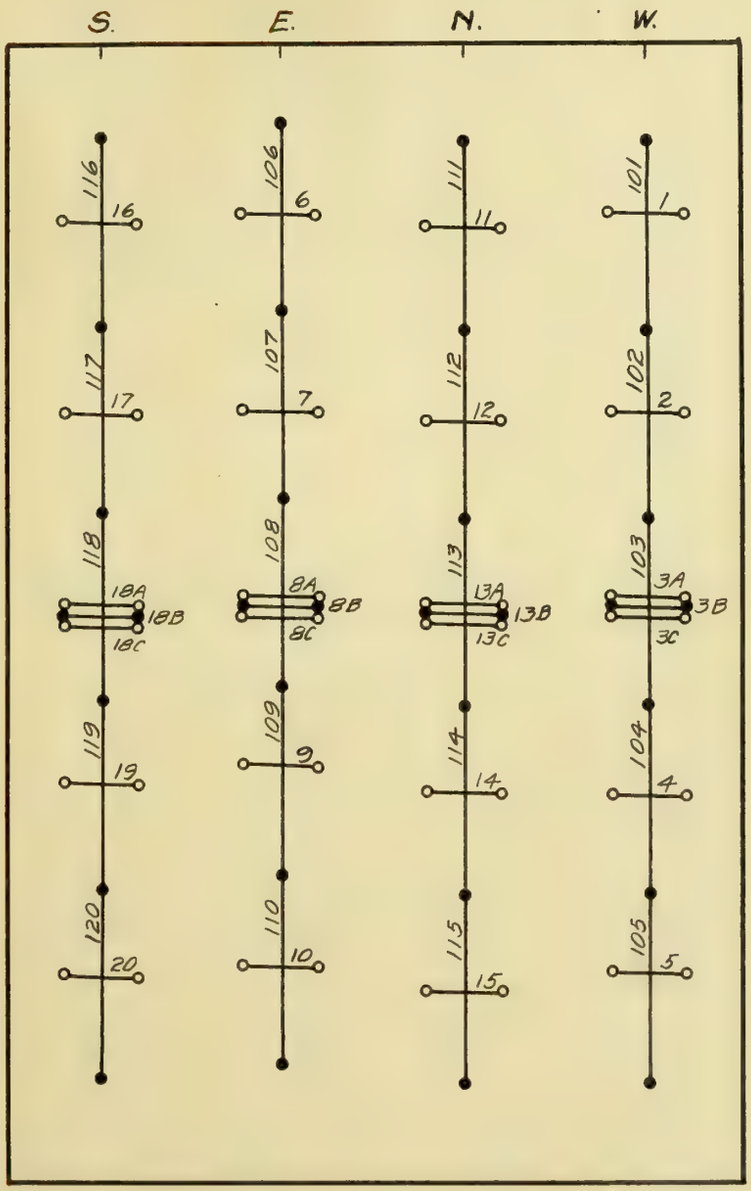


- Gage lines on concrete 10" & 4"
- Gage lines on steel 4"

Scale: 1" = 10"

COL. 8912

Length $60\frac{1}{2}$"

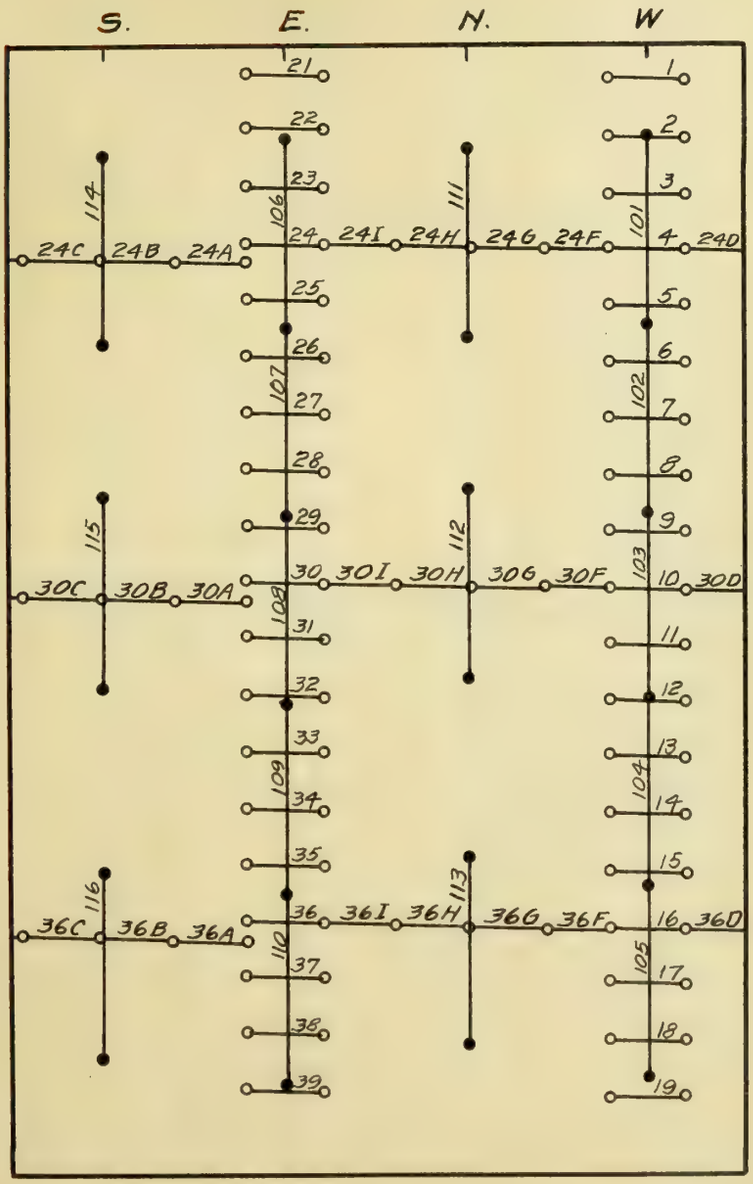


- Gage line on concrete 10" & 4"
- Gage lines on steel 4"

Scale: 1" = 10"

COL. 8913

Length 60"
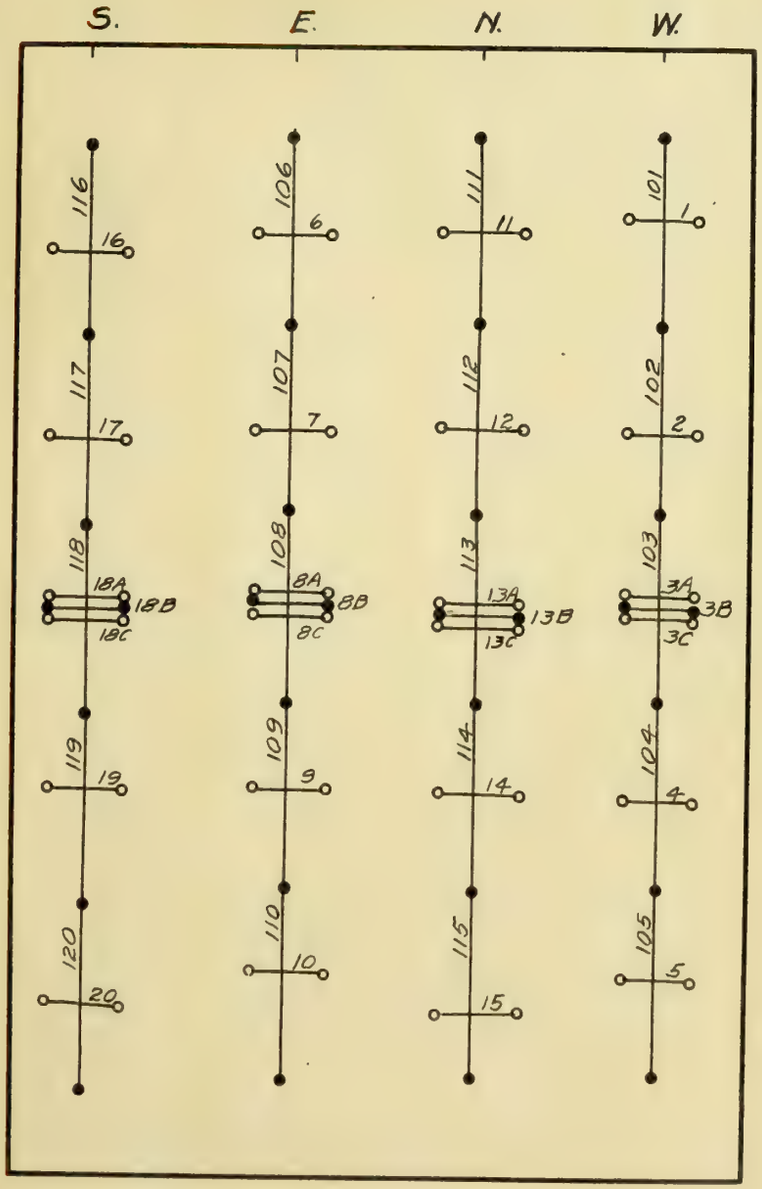


• Gage line on concrete 10"

◦ Gage line on steel 4"

Scale: 1"=10"

COL. 8914

Length $60\frac{7}{8}$"

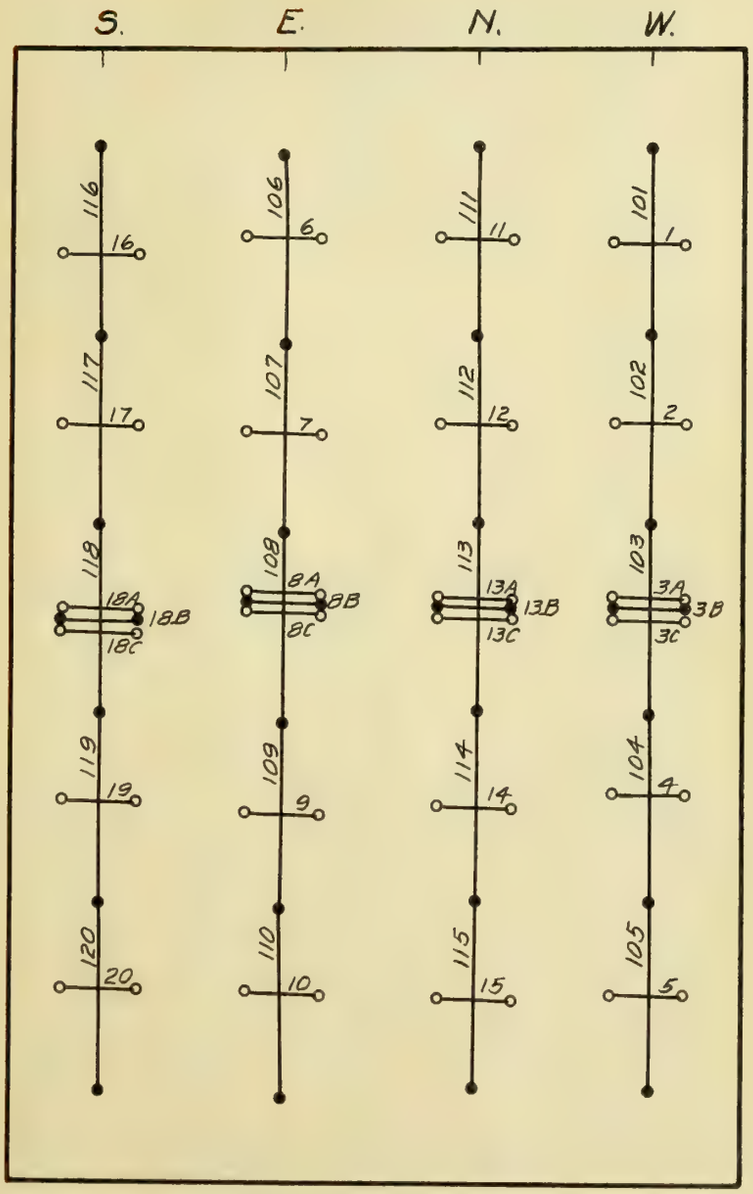


- Gage line on concrete 10" & 4"
- Gage line on steel 4"

Scale: 1" = 10"

COL. 8915

Length $60\frac{1}{8}$"

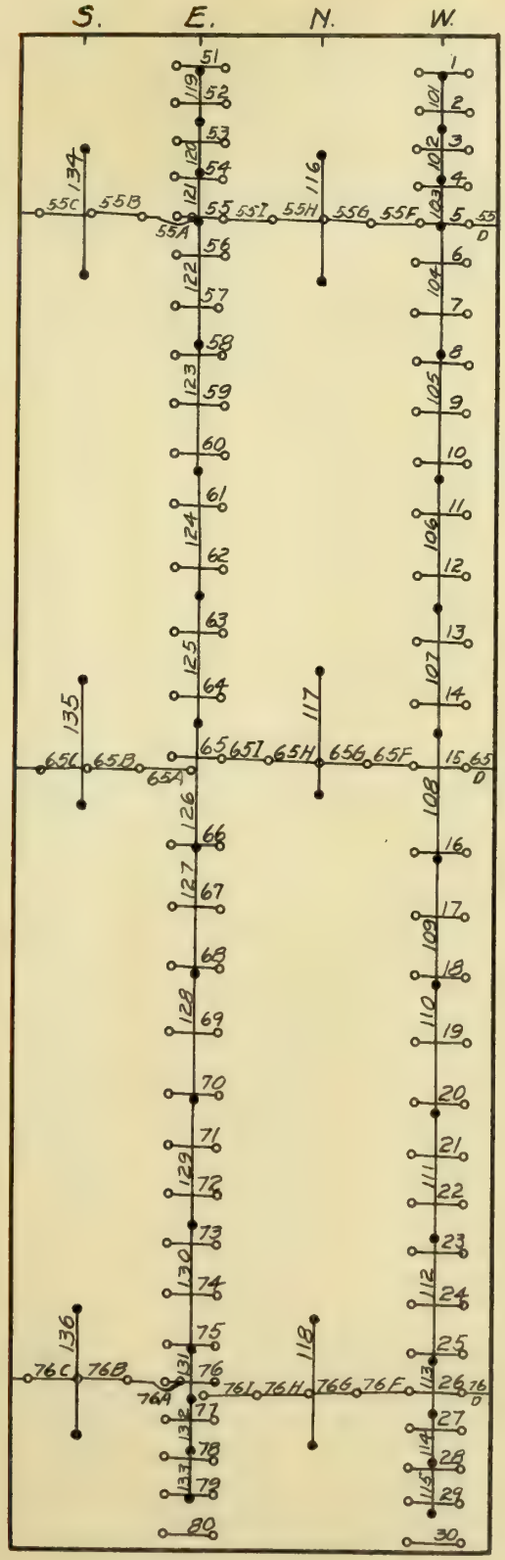


- Gage line on concrete 10" & 4"
- Gage line on steel 4"

Scale: 1" = 10"

COL. 8916

Length 10'-½"



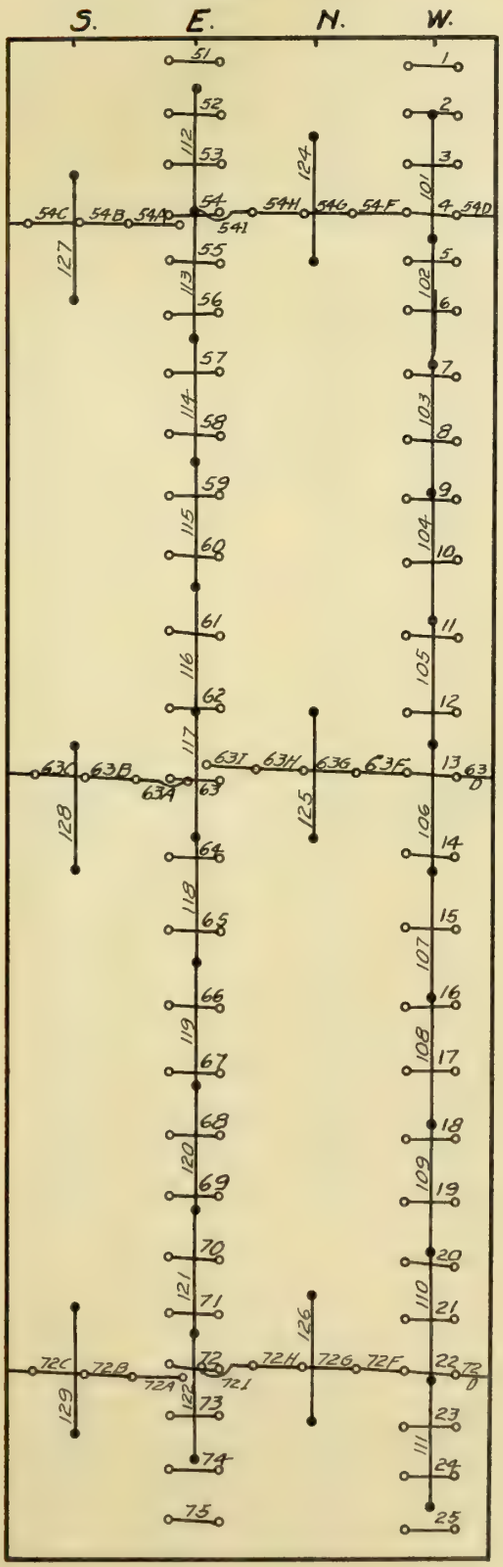
• Gage lines on concrete 10" & 4"

○ Gage lines on steel. 4"

Scale: 1"=15"

COL. 8917

Length 10'-1½"



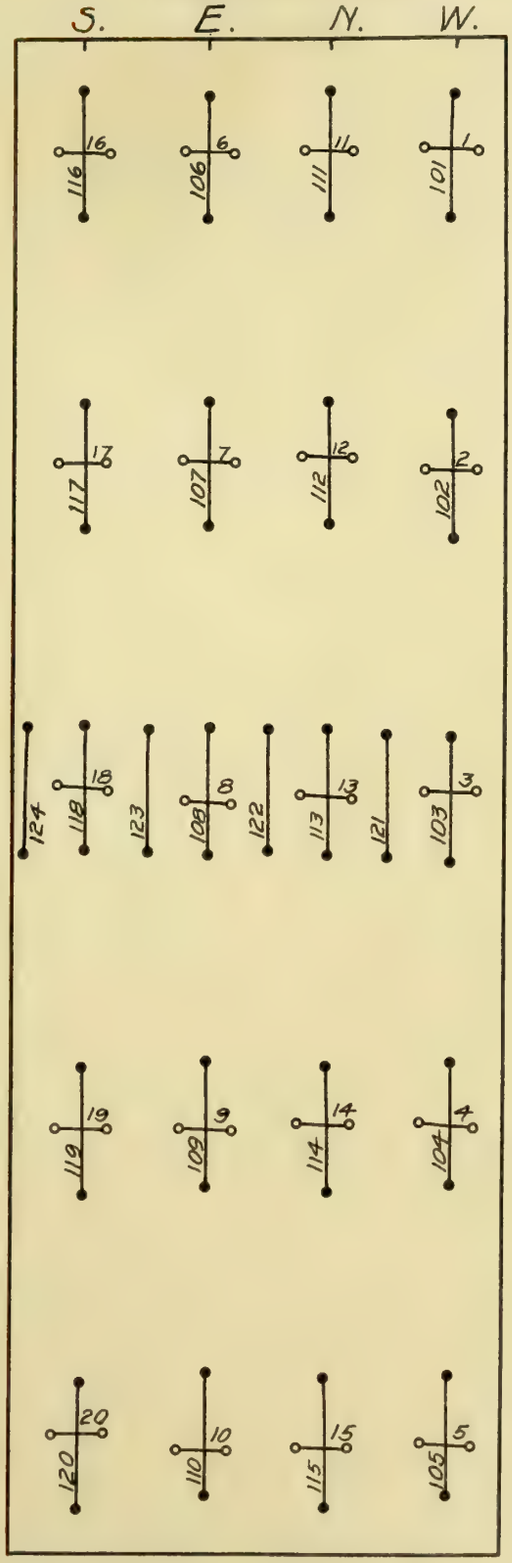
• Gage line on concrete 10"

○ Gage line on steel 4"

Scale: 1" = 15"

COL. 8918

Length 10'-1¼"



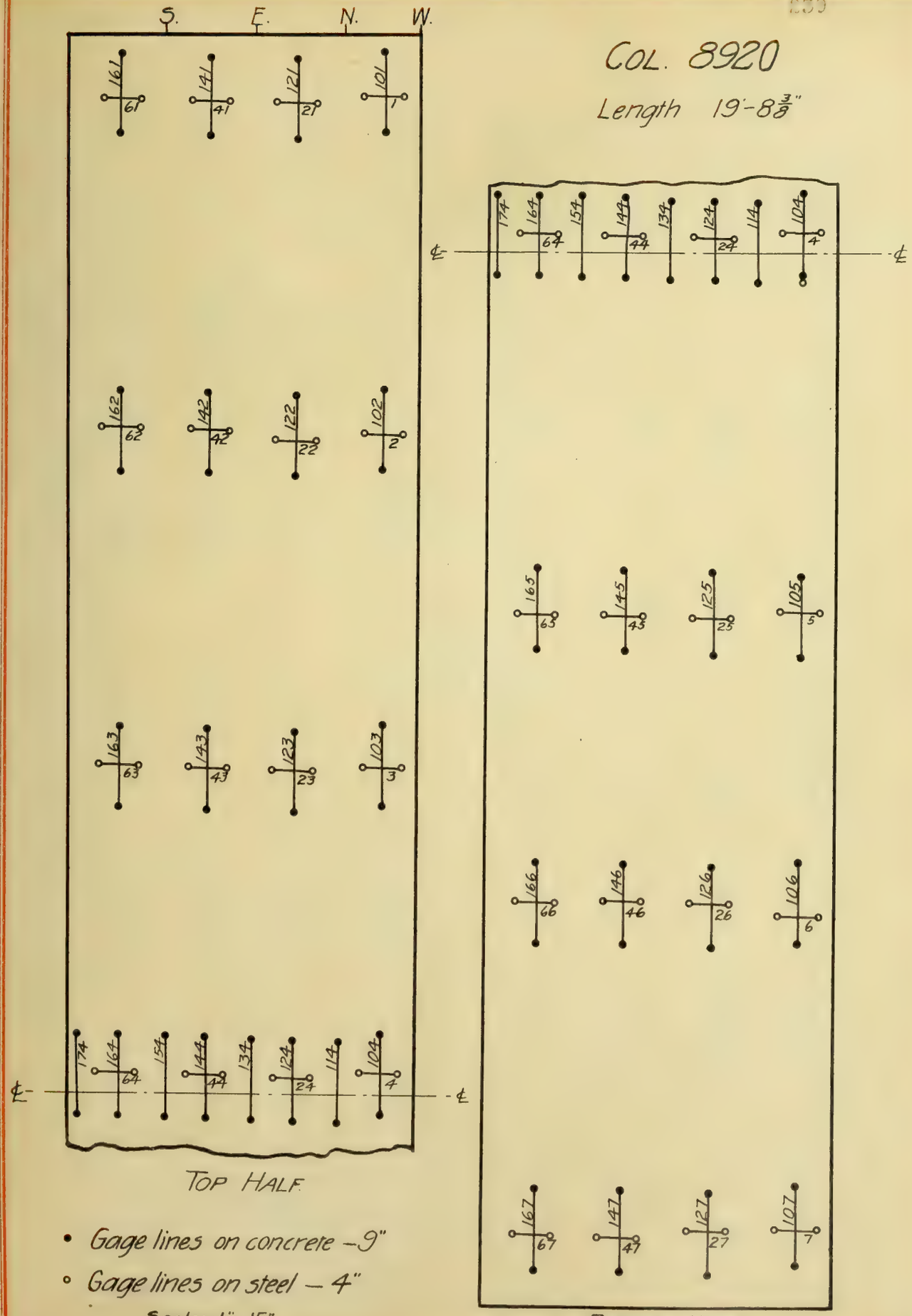
• Gage line on concrete - 10"

○ " " " steel - 4"

Scale: 1"=15"

COL. 8920

Length 19'-8 3/8"

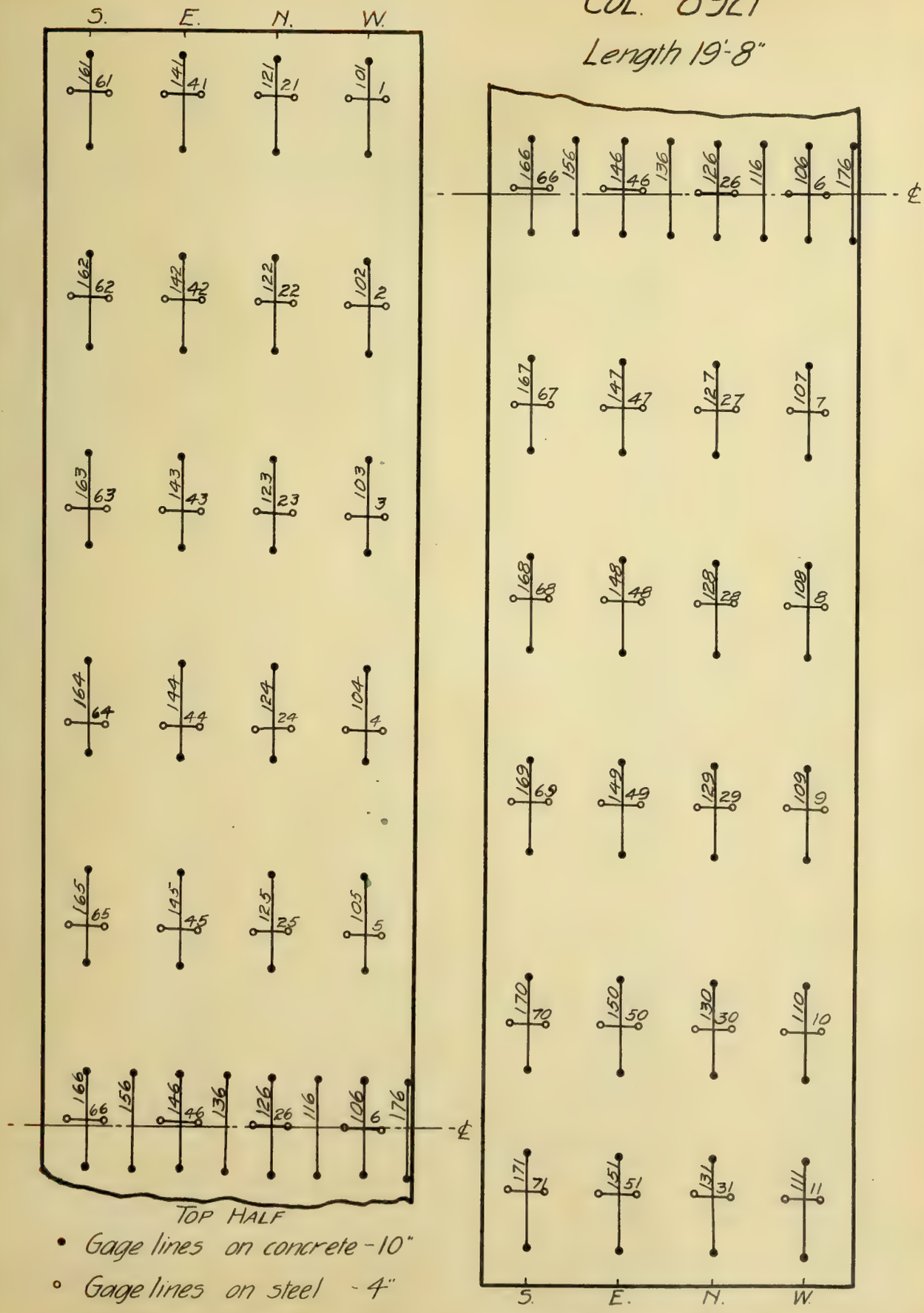


- Gage lines on concrete – 9"
- Gage lines on steel – 4"

Scale: 1" = 15"

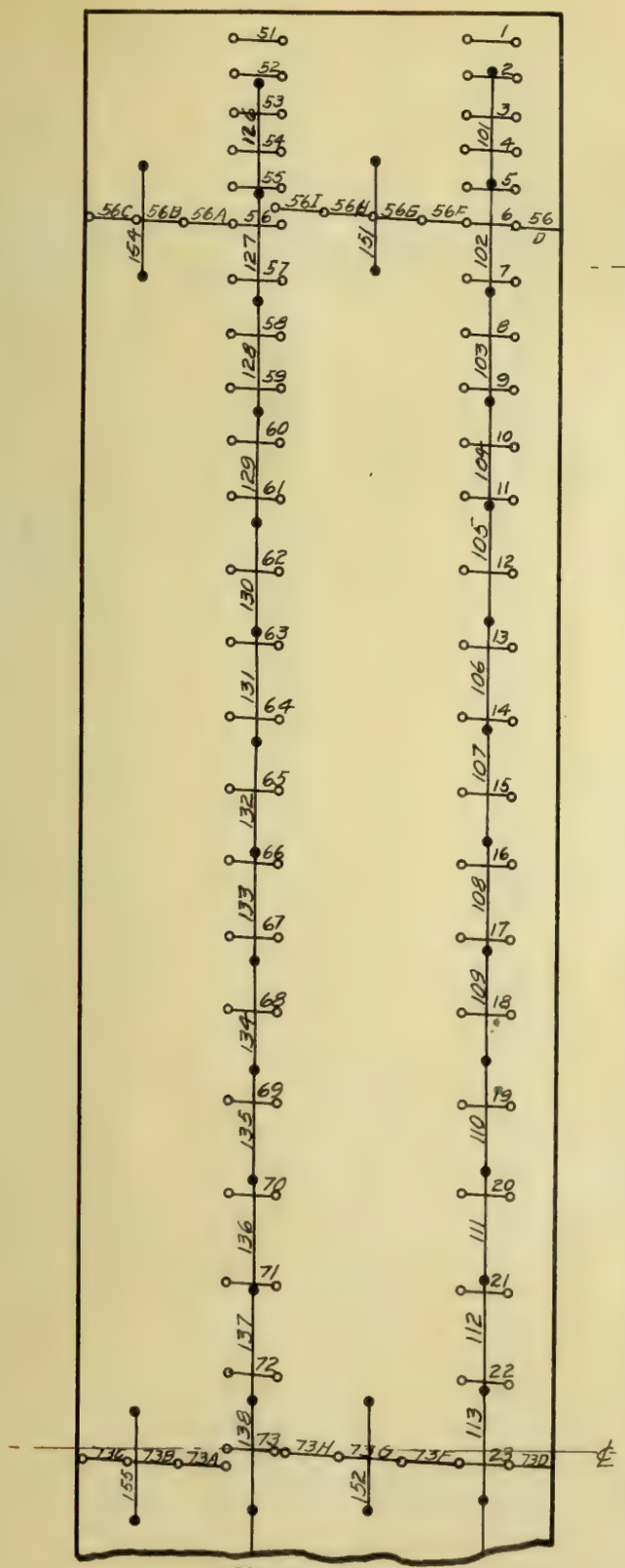
COL. 8921

Length 19'-8"



COL. 8922

Length 19'-8"



TOP HALF

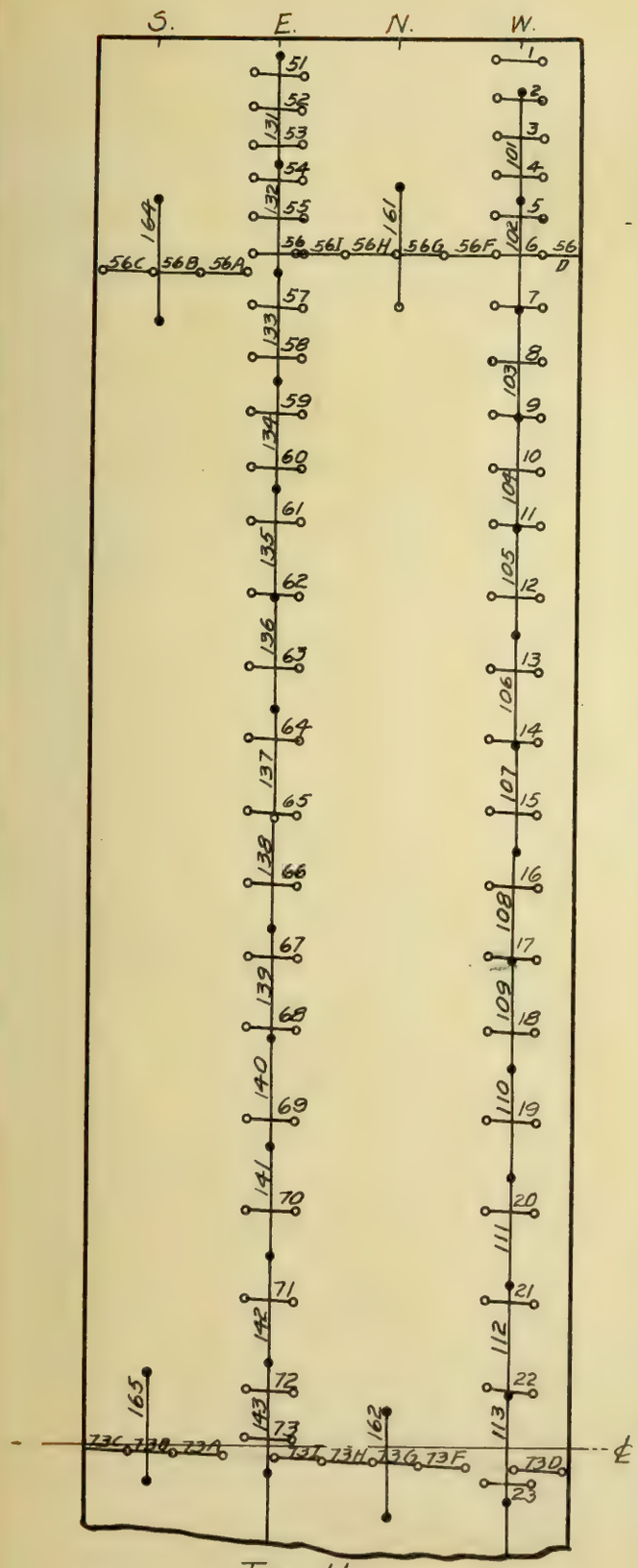
BOTTOM HALF

- Gage lines on concrete -9"
- Gage lines on steel -4"

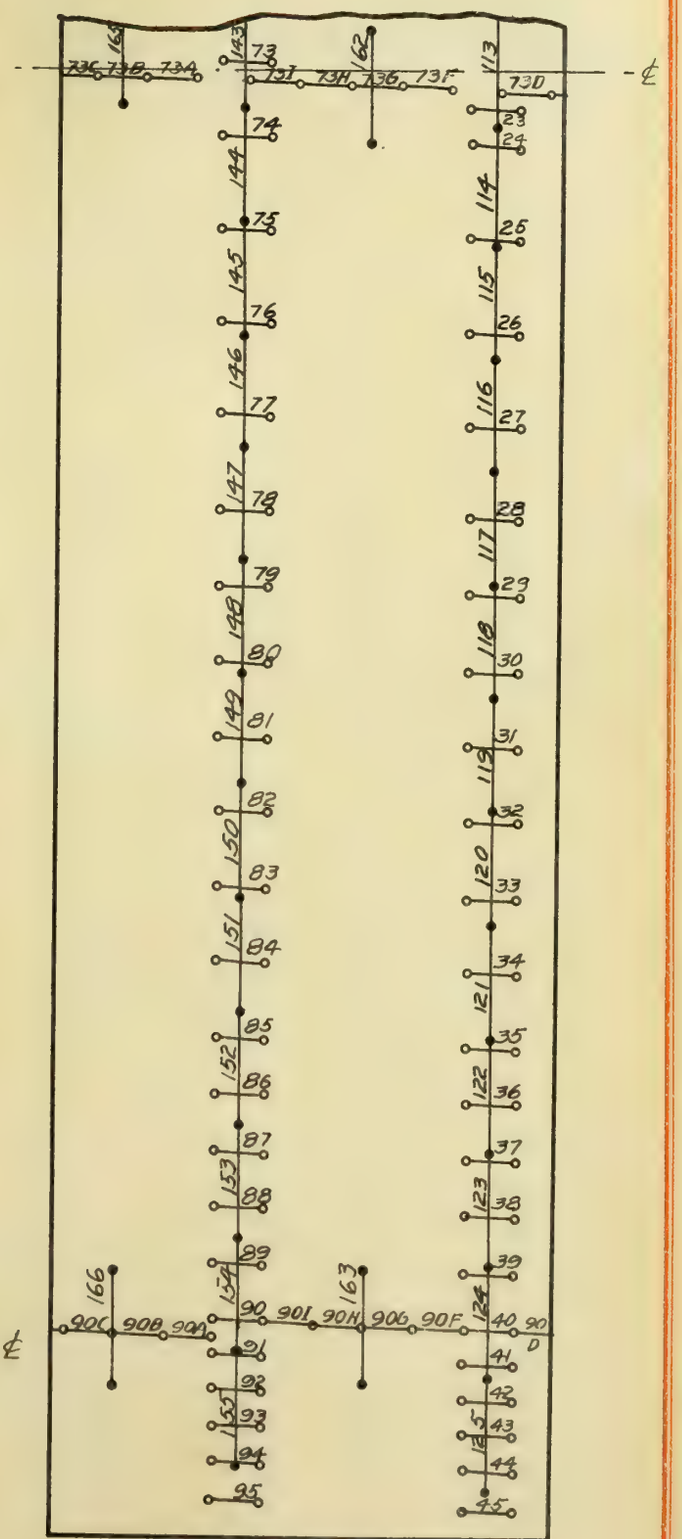
Scale 1"=15"

COL. 8923

Length 19'-6"



TOP HALF



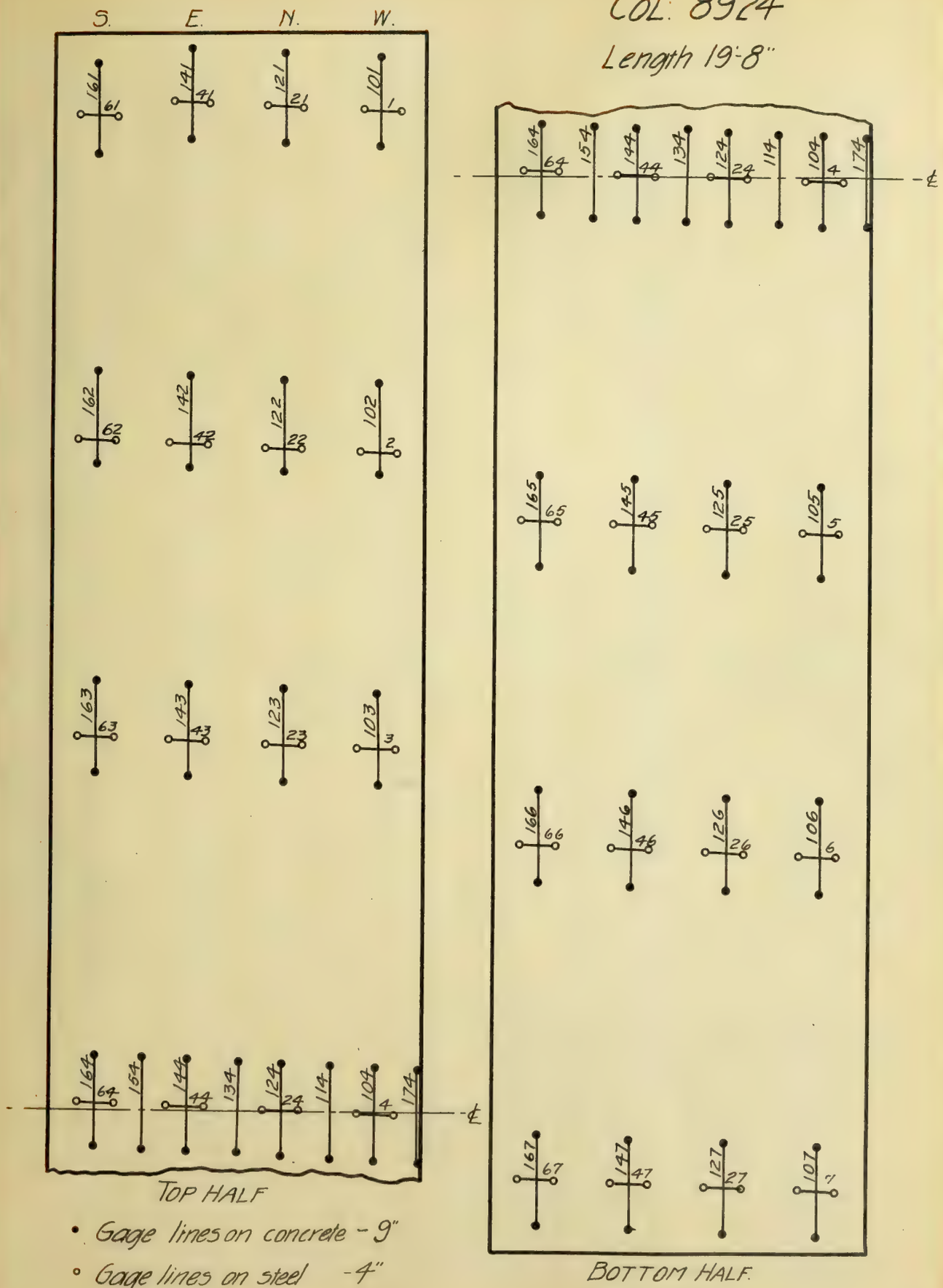
BOTTOM HALF

- Gage lines on concrete - 9"
- Gage lines on steel - 4"

Scale 1" = 15"

COL: 8924

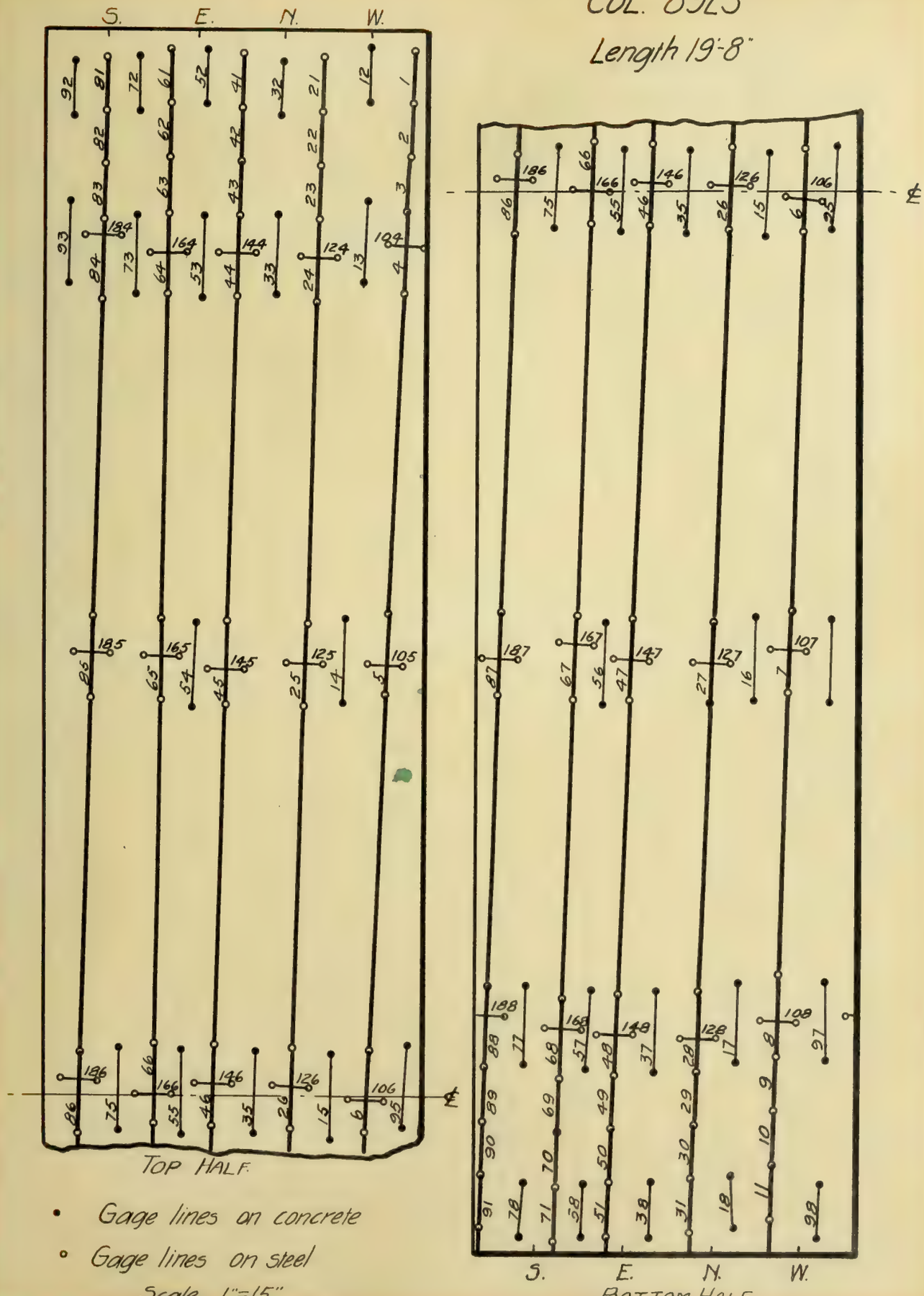
Length 19'-8"



- Gage lines on concrete - 9"
- Gage lines on steel - 4"

COL. 8925

Length 19'-8"



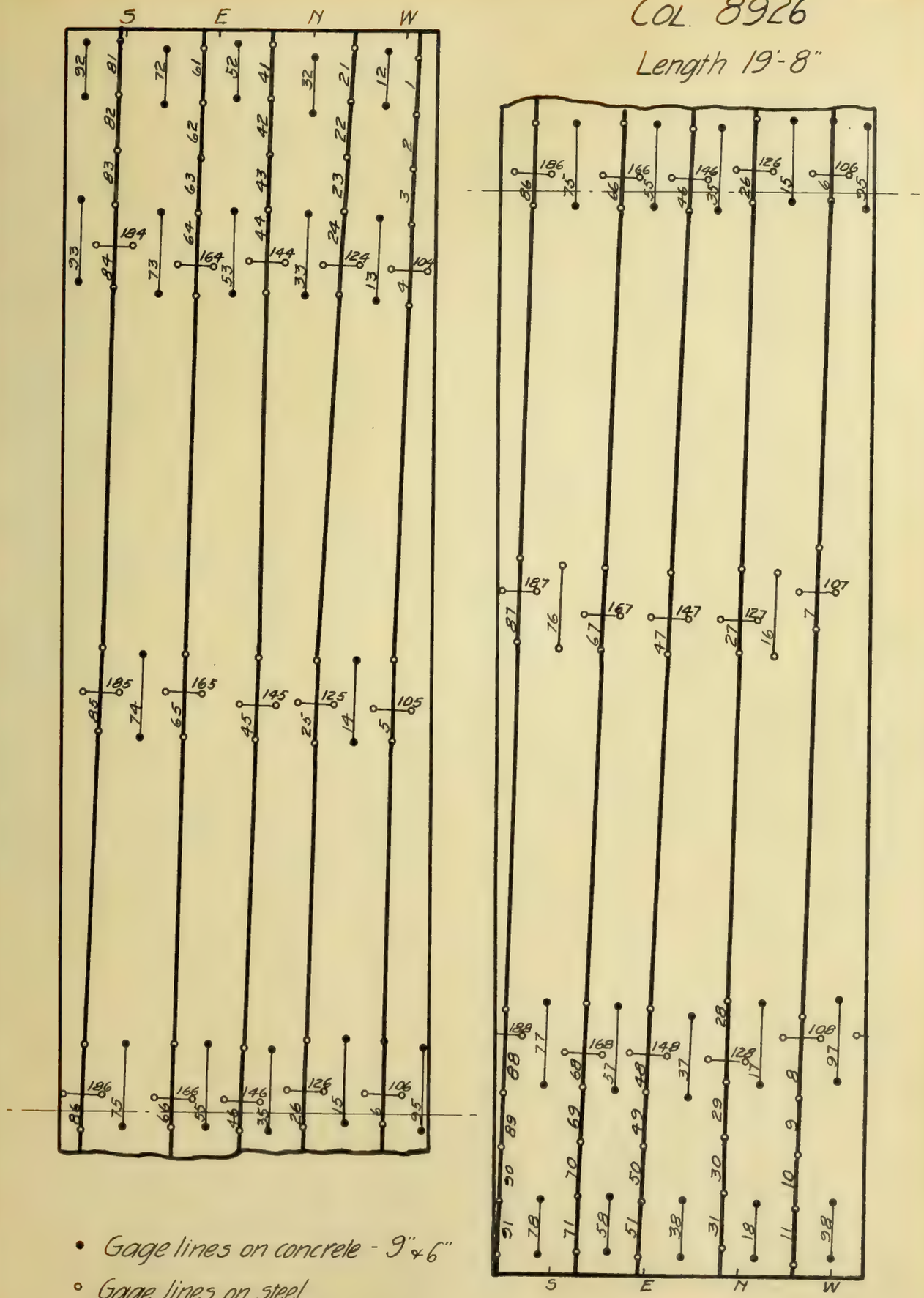
• Gage lines on concrete

° Gage lines on steel

Scale 1"=15"

COL. 8926

Length 19'-8"



• Gage lines on concrete - 9" & 6"

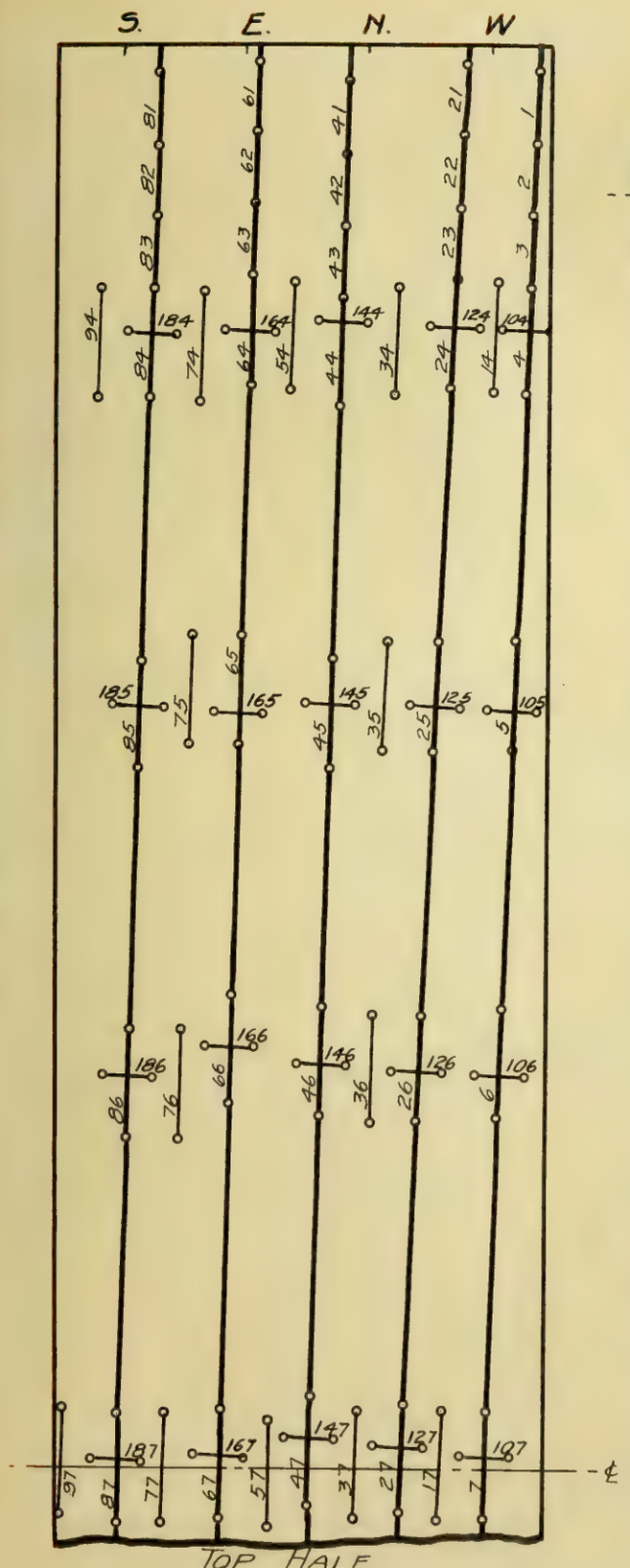
° Gage lines on steel

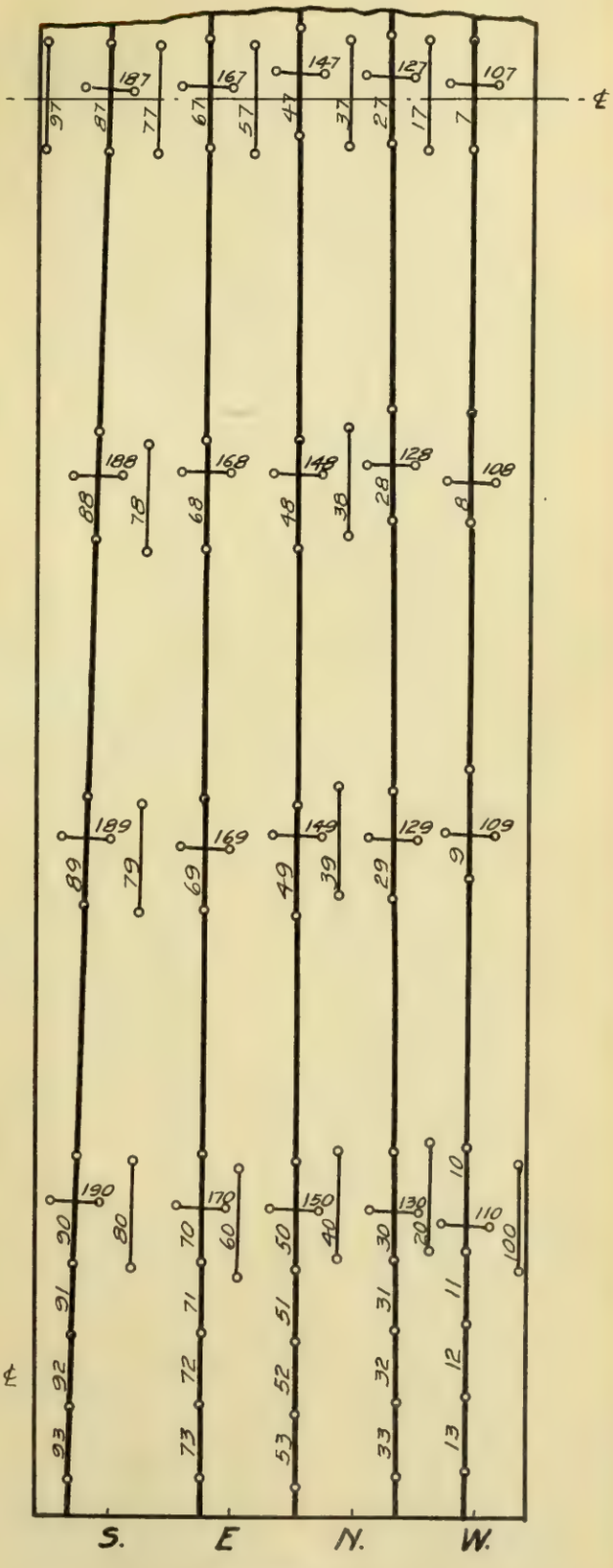
Scale: 1" = 15"

BOTTOM HALF

COL. 8927

Length 19'-8 3/8"





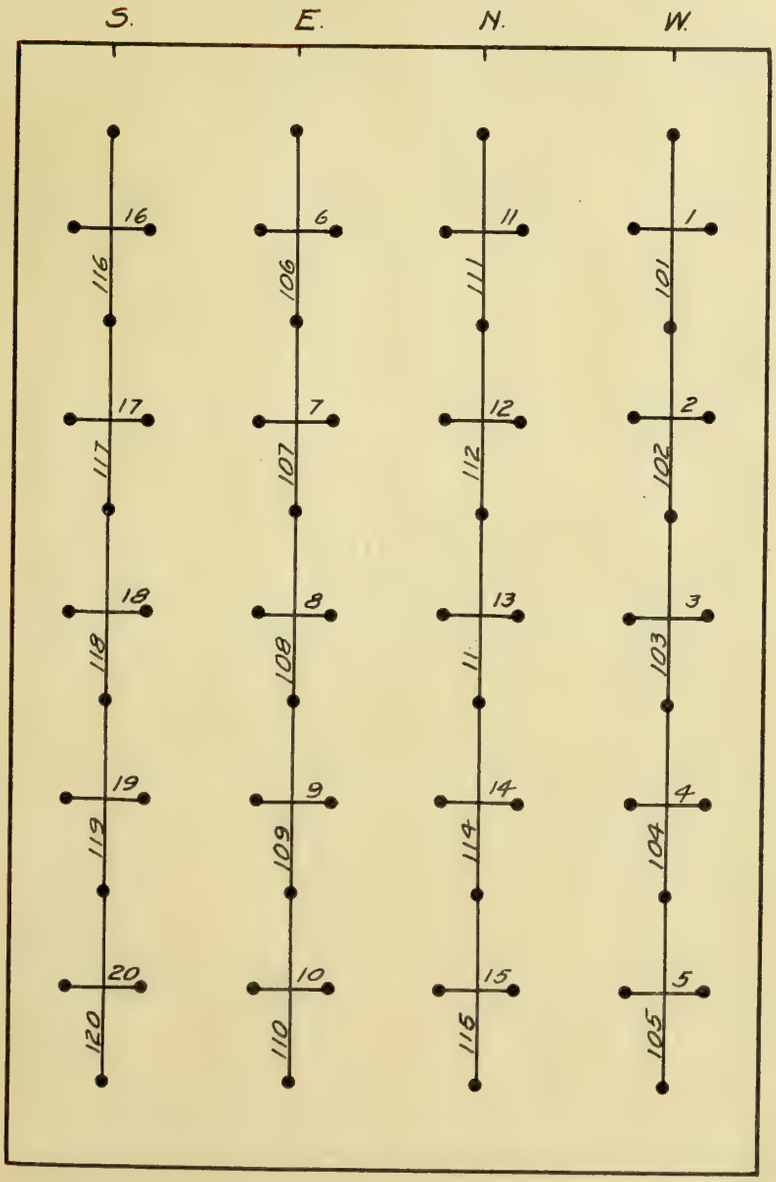
• Gage lines on concrete 9"

◦ Gage lines on steel 9", 6", 4"

Scale: 1" = 15"

COL. 8928

Length 59½"

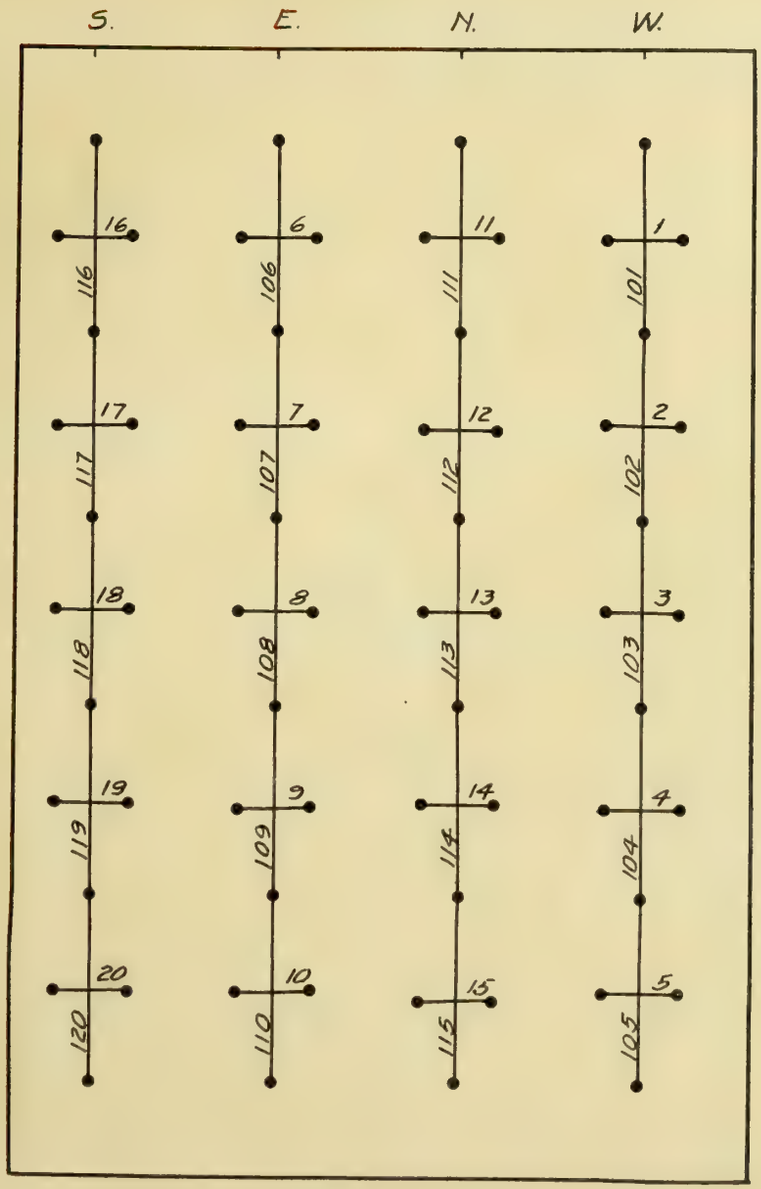


• Plugs in concrete

Long. gage length 10"
Lateral gage length 4"
Scale: 1"=10"

COL. 8929

Length $59\frac{7}{8}$"

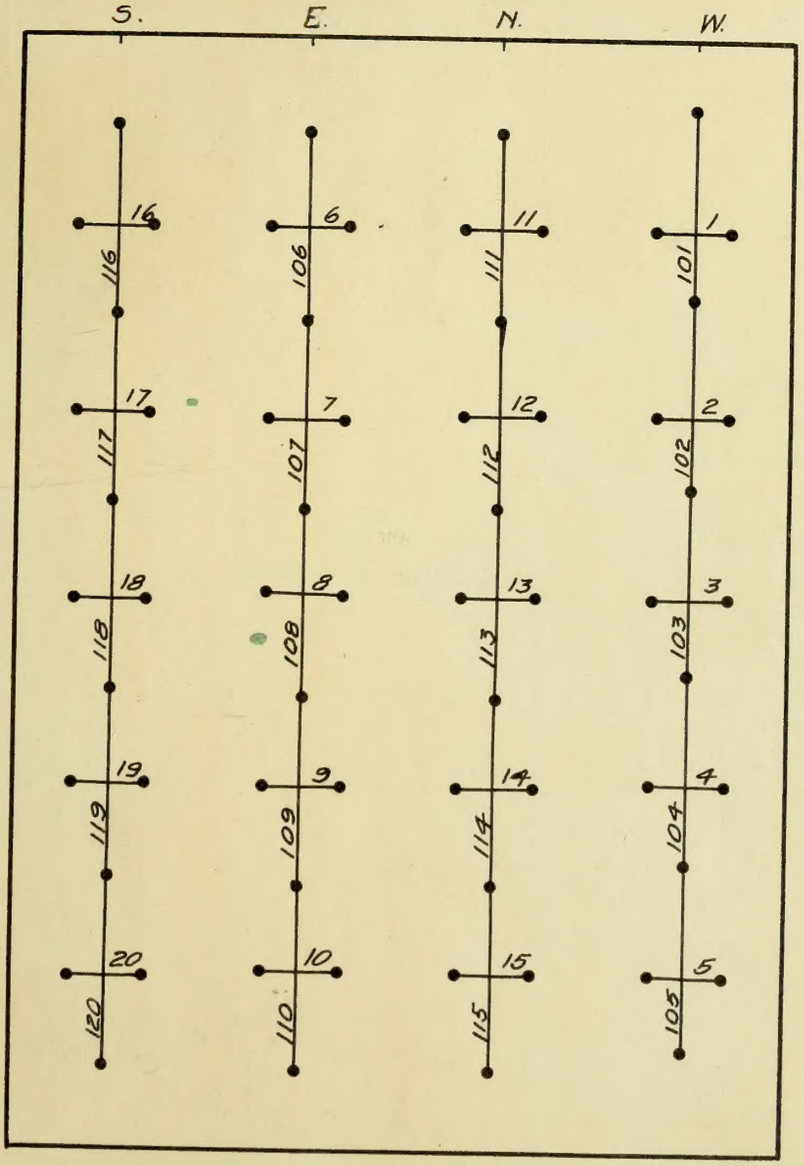


• Plugs in concrete

Long. gage length 10"
Lateral gage length 4"
Scale: 1"=10"

COL. 8930

Length 59¼"



• Plugs in concrete

Long. gage Length 10"
Lateral gage length 4"
Scale: 1"=10"

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